Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Electronic Systems

Simen Domaas

Enhancing Ski Film Production Using Dynamic Visual Effects

Master's thesis in Electronic Systems Design and Innovation
Supervisor: Andrew Niels Perkis
Co-supervisor: Øyvind Sørdal Klungre
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Abstract

In a market where advanced film production resources and numerous sharing platforms intensify competition among ski filmmakers, standing out and capturing viewer interest can be challenging. This work introduces an innovative approach to ski filmmaking by integrating LED technology with real-time sensor data and digital effects created using the game development platform Unity. An object detection model extracts information from videos to enable automatic positioning of effects in the post-editing.

A field test and an interview with film industry professionals provided valuable feedback, highlighting the system's potential and areas for improvement. In addition, a video[1] was created using recordings from the field test and used in a survey that included 34 respondents from within and outside the skiing community. Results from the survey demonstrated promise as 58.8% of participants gave a rating of 4 or 5, with 5 being the most innovative, when asked to rate how much it stood out from other videos they had seen, and 52.9% rated their interest in watching a longer video with a similar concept as 4 or 5 out of 5, with 5 being the highest interest. For most metrics, the results showed little correlation between the respondents' interest in freeskiing and perceived video quality.

The interview participants stated that the LED system's dynamic lighting was innovative and had great potential for use in large-scale productions. However, further enhancements are needed, particularly in lighting and detection accuracy. Future developments should focus on increasing the number of LEDs, detecting more advanced movements, making the hardware more robust, and refining detection models for low-light conditions.

[1]Edited video from field test: https://youtu.be/F8SjDWHWR2g

Sammendrag

I et marked hvor avanserte filmproduksjonsressurser og bruk av delingsplattformer øker konkurransen blant skifilmskapere, kan det være utfordrende å skille seg ut og fange interessen til seere. Dette arbeidet introduserer en innovativ tilnærming til skifilmproduksjon ved å integrere LED-teknologi med sanntids sensordata og digitale effekter laget med spillutviklingsplattformen Unity. En model for objektdeteksjon brukes til å hente ut informasjon fra videoer for å muliggjøre automatisk posisjonering av effekter i etterredigeringen.

En felttest og et intervju med filmbransjepersonell ga verdifulle tilbakemeldinger og tydeliggjorde systemets potensial og forbedringsområder. I tillegg ble en video[2] laget ved hjelp av opptak fra felttesten og brukt i en undersøkelse med 34 respondenter som hadde varierende interesse for ski og frikjøring. Resultatene fra undersøkelsen var lovende. 58.8% av deltakerne ga en vurdering på 4 eller 5, hvor 5 er mest innovativt, da de ble spurt om hvor mye videoen skilte seg ut fra andre videoer de hadde sett, og 52.9% vurderte egen interesse for å se en lengre video med et lignende konsept som 4 eller 5 av 5, med 5 som høyeste interesse. For de fleste målingene viste resultatene liten sammenheng mellom respondentenes interesse for frikjøring og oppfattet videokvalitet.

Intervjuobjektene uttalte at LED-systemets dynamiske belysning var innovativt og hadde stort potensial for bruk i storskala produksjoner. Samtidig kom det fram at det er behov for ytterligere forbedringer, spesielt innen belysning og deteksjonsnøyaktighet. Videre utvikling bør fokusere på å øke antall LED-lys, oppdage mer avanserte bevegelser, gjøre det fysiske oppsettet mer robust og utbedre modeller for deteksjon i mørke omgivelser.

[2] Redigert video fra felttest: https://youtu.be/F8SjDWHWR2g

Preface

This work concludes a five-year study in Electronic Systems Design and Innovation at the Norwegian University of Science and Technology (NTNU). The assignment was given by the Department of Electronic Systems and supervised by Professor Andrew Niels Perkis and Øyvind Sørdal Klungre.

Working on a project that combines my interests in skiing and technology has been exciting, and I believe that with further development, this project has the potential to deliver excellent results.

Special thanks to Kaja Vik and Dennis Risvoll from Frys Film for their assistance during testing and insightful contributions, which significantly aided the development of this work.

Thanks should also go to Erik Aurmo for granting us access to Lemonsjøen Alpine Center and to Kristian Moen for participating as a skier during field testing.

Thank you to my supervisors, Andrew Niels Perkis and Øyvind Sørdal Klungre, for guidance throughout this project.

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List of Acronyms

AHRS Attitude and Heading Reference System.

API Application Programming Interface.

AR Augmented Reality.

COCO Common Objects in Context.

DMP Digital Motion Processor.

DMX Digital Multiplex.

HSV Hue, Saturation, Value.

I2C Inter-Integrated Circuit.

IMU Inertial Measurement Unit.

IOU Intersection Over Union.

JSON JavaScript Object Notation.

LED Light Emitting Diode.

PLA Polylactic Acid.

RAM Random-Access Memory.

RGB Red, Green, Blue.

SD Secure Digital.

SDG Sustainable Development Goals.

SRAM Static Random-Access Memory.

VR Virtual Reality.

YOLO You Only Look Once.

1 Introduction

Over the past few decades, the process of making films has undergone significant transformations driven by advancements in multimedia technologies. While traditional filmmaking once relied on basic tools and techniques, as seen in Figure 1, today's industry uses high-definition digital cameras and advanced technology, expanding the scope for creative storytelling. Digital cameras and editing software have allowed filmmakers to explore effects that were once out of reach. Additionally, drones have revolutionized the capture of dynamic aerial scenes [1], [2]. These technologies allow for stunning aerial shots and detailed captures of fast-moving scenes, setting new standards, especially for action-packed films.

Figure 1: On-set photo from the 1927 film production of *The Great Leap*, illustrating the early techniques of filmmaking. Image from Picryl - a public-domain media search engine.

Adopting virtual reality (VR) and augmented reality (AR) technologies in filmmaking represents other advancements in the industry's evolution [3]–[6]. These technologies are changing how filmmakers plan and carry out their projects, providing immersive experiences that were once impossible. VR allows audiences to step inside the movie environment, offering a 360-degree interactive experience, while AR adds digital elements to real-life footage, making scenes more interesting by adding computer-generated features that enhance the story. These advancements are redefining how viewers can engage with video, and they expand the toolkit filmmakers can utilize, enabling them to merge digital effects with real-world scenes. Integrating such effects can be simplified using digital platforms and software [6]–[12]. Even with advanced technology being more accessible, filmmakers still face the challenge of standing out in a crowded market.

Viewers expect high-quality visuals and storytelling, pushing filmmakers to find new ways to impress.

This work will explore how the combination of dynamic light and digital effects can be used in ski filmmaking, a niche yet growing area of sports cinematography, to make ski videos more visually appealing and stand out from previously produced films. It will apply these technologies in ski films and discuss their potential to change the filmmaking process. The work presents the development and evaluation of an electronic system design used to create visual effects during the recording of ski films and how these effects are combined with post-production editing.

2 Background

Ski films unite the skiing community, creating shared experiences and a sense of affiliation [13]. They support athletes, photographers, cinematographers, and others in the industry. In addition to showcasing extreme skiing, these films capture the beauty and challenges of the sport. Ski films can inspire future generations and increase the interest and passion for skiing.

The advancements in camera technology and the widespread availability of drones have significantly elevated the quality of ski films and other sport-related cinematography. Modern cameras offer high-resolution imagery and better stabilization, allowing for sharper and more dynamic footage. Drones have become less costly and provide unique aerial views and the ability to capture cinematic shots that were previously unattainable. These technological improvements not only raise the standard of what is visually possible but also significantly influence sports consumers' viewing experiences [14]. As a result, viewers have grown accustomed to high-quality productions, making it increasingly challenging for filmmakers to stand out in a market where exceptional is the new norm.

The strong competition from other quality ski film producers is amplified by the rise of social media and sharing platforms like YouTube because they make content more available [15]. These platforms also allow viewers to scroll through short video clips instead of committing to longer films. This increases the need to create something that has not been seen before to draw viewers' attention.

The heightened viewer expectation demands technical skill and creative innovation from those producing ski films. Although risk-seeking is not necessarily the goal itself [16], freeskiers often attempt more daring stunts to ensure their videos stand out. An example of this is the high altitude and steep skiing seen in the ski film *La Liste* [17]. Figure 2 is an image captured during the recording of this film, showing two skiers dwarfed by the enormous and close-to-vertical mountainside.

This work introduces a new way to make ski videos using colored lights, sensor data, and post-editing effects to add a creative twist. This combination gives filmmakers an innovative tool to create visually stunning content that captivates viewers through vivid colors and patterns. Instead of relying solely on high-risk maneuvers, this method leverages technology to make ski videos more distinctive and engaging. While several projects have utilized sensor data to analyze skiing parameters [18]–[21], there has been little recorded exploration of incorporating real-time sensor data to enhance ski filmmaking.

Figure 2: Image of the freeskiers Jérémie Heitz and Sam Anthamatten from the ski film *La Liste.* The skiers can be spotted close to the top from the snow spray behind their skis. ©Tero Repo. Used with permission.

A similar project that marked a significant development in innovative ski filmmaking is found in [22]. This video established a new standard for creativity in ski films by using LED-lit ski suits and advanced lighting techniques to produce captivating visual effects on snowy terrains. The combination of technology and artistry showed the potential for using technological innovations to improve ski videos. Building on some of the concepts from [22], this project extends the use of LED lights in ski videos by introducing dynamic changes to the lighting that responds in real-time to the skier's movements. This dynamic adaptation allows the lights to change colors and patterns in sync with the skier's actions, creating a more interactive experience. These developments can improve the narrative quality of ski videos, as the changing lights directly mirror the skier's maneuvers and can create a dynamic intensity that progressively intensifies in sync with added music.

The Unity platform, a versatile and powerful platform typically used for game development in 2D or 3D [6], is used in this project to introduce a new approach to the post-production phase of ski filmmaking. This method differs from the more popular approach of editing videos using editing software like Adobe Premiere Pro [23] and DaVinci Resolve [24] but enables exploration of Unity's video-editing capabilities. It allows for the integration of unique visual effects that react to the skier's movements, which can increase the visual impact of the LED system. This work aims to utilize Unity to combine digital effects with recordings of a skier to create interesting ski dynamics and particle effects. This includes utilizing Unity's particle systems to simulate artificial snow spray. Such innovative use of technology complements the significant changes that augmented reality brings to film production, as discussed in [5]. Mixing post-editing effects with dynamic light changes captured during recording adds a new dimension to storytelling in ski films, enabling filmmakers to integrate digital effects with live-action scenes. The Unity project and other scripts developed in this work can be found here: https://github.com/simendo/unity_freeride.

The goal of this work is to change how people enjoy ski films and help filmmakers be unique through creativity and new ideas. By integrating LED lights with real-time sensor data, the project creates dynamic lighting effects that enhance the overall visual impact. Furthermore, the use of Unity for editing ski videos and creating artistic and captivating content is explored. Through these technologies, this work aims to improve the quality and distinctiveness of ski films. The work primarily focuses on videos recorded at nighttime, as dark surroundings can improve the light effect. The design and evaluation of the LED system and the editing performed in Unity are described. In addition, this work presents an object detection model trained on a custom dataset that syncs the Unity effects' positioning with the skier's placement and movement. In-depth interview techniques [25]–[27] and feedback from a questionnaire are used to evaluate the performance of these technologies in real-world settings.

This work aligns with some of the United Nations Sustainable Development Goals (SDGs) [28], particularly focusing on promoting innovation, which is one of the sub-goals of SDG 9, and ensuring responsible consumption and production (SDG 12). Moreover, the project intends to generate interest in freeskiing, which could encourage people to participate in outdoor skiing activities, thus supporting the objective of SDG 3 to ensure healthy lives and promote well-being for all.

This work is organized into the following sections:

- *Design* - This section presents details about the design of the LED system. It includes hardware and software components and system architecture, in addition to the detection model's development.
- *Method* - This section describes how Unity is used for post-editing effects. It also presents methods for evaluating the quality of the designed system.
- *Verification and Validation* - The verification process is explained in this section, covering the functional testing of the LED system, the evaluation of the detection model, and the field tests conducted to assess system performance.
- *Results* - This section presents the results from the verification and field tests, including the performance metrics of the LED system and the detection model, as well as feedback from the survey and interviews.
- *Discussion* - The results are discussed in detail, highlighting the strengths and weaknesses of the system. This section also addresses the practical challenges encountered and suggests improvements for future work.
- *Conclusion* - The final section summarizes the key findings, reflects on the potential impact of the work, and proposes directions for further research.

3 Design

This section describes the design and development of a system for creating visual effects in ski films. Figure 3 is a block diagram of the project's components, including an LED system, the use of an object detection model, and editing in Unity. The subcomponents of the LED system are colored light pink in the block diagram. Information is extracted from video recordings of a skier wearing the LED system using detection models. This information is used to add effects to the video in Unity. The subcomponents of the detection process are colored green, and the subcomponents of the Unity editing are blue.

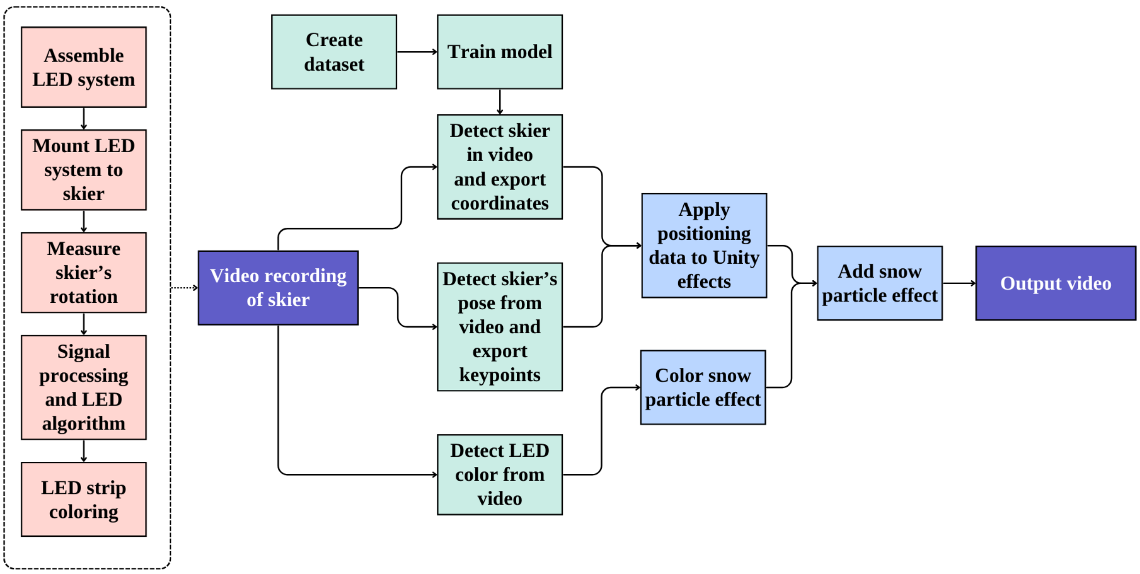


Figure 3: Block diagram illustrating the project layout.

3.1 LED System

The following describes the hardware and signal processing in a light-emitting diode (LED) system. This system is designed to enhance ski videos by adding dynamic visual effects that make the footage more engaging and entertaining. By strapping LED strips onto a skier, the system creates a visual effect that improves the overall aesthetics of the video. The LED colors respond to the skier's movements, providing a real-time representation of slope maneuvers.

Figure 4 illustrates the components of the LED system and their placement. A microcontroller interprets the data from an inertial measurement unit (IMU) and determines what colors the LED strips, which are placed between the shoulder and wrist on each side, should have. The system's power supply is also placed on the skier's abdomen. Communication between the microcontroller and the LED strips is done using wires.

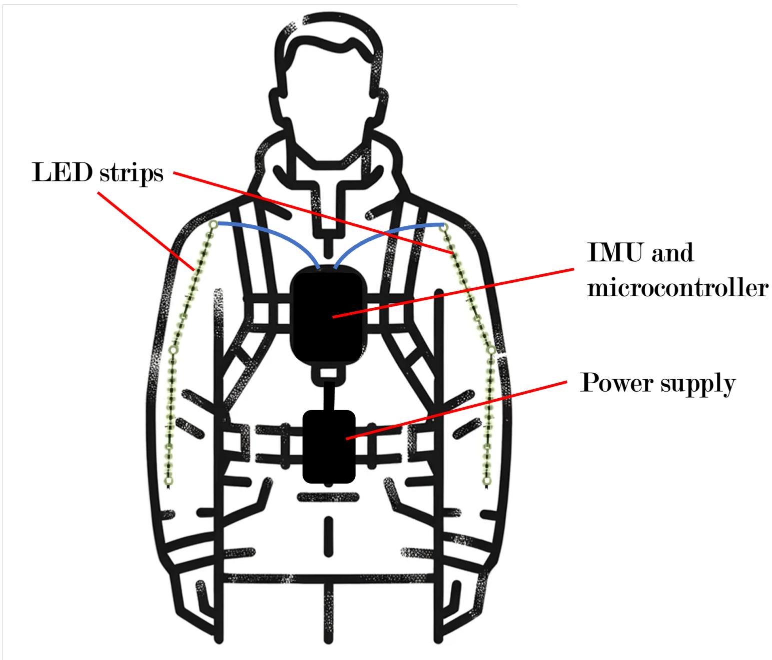


Figure 4: The main components of the LED system are the microcontroller and sensor system, which are mounted on the chest, in addition to the power supply, and the two LED strips - one on each arm. This image was created with the assistance of the image generator DALL-E 2.

An important aspect of this LED system is its reusability and energy efficiency, which contribute to sustainable filmmaking practices. This aligns with the UN's SDG 12: Responsible Consumption and Production. Designing a system that can be used multiple times reduces electronic waste, promoting more sustainable resource use. Additionally, the energy-efficient LEDs minimize power consumption, further supporting environmental sustainability.

3.1.1 Hardware

Table 1 describes the components used for the LED system.

Component	Type	Description
LED strips	WS2812B[29]	Two strips of 44 addressable pixels. Version: IP-64
Microcontroller Board	Arduino Uno [30]	Arduino Uno Rev 3 SMD
Power supply	Silicon Power QS55 [31]	Powerbank - 20 000mAh
IMU	MPU6050[32]	3-axis accelerometer and 3-axis gyroscope.
Power supply module	XD-42	2 Channel 3.3V 5V Breadboard Power Supply Module
Mounting straps		Mammut Barryvox beacon straps
Pull-up resistors	Fixed resistors	2 resistors at 1kΩ

Table 1: Components of LED system.

3.1.1.1 Microcontroller Board

The Arduino Uno was primarily chosen for its ease of use and compatibility with WS2812 LED strips. Its straightforward development environment simplifies the process of writing, uploading, and debugging code. The availability of libraries such as the Adafruit NeoPixel library[33], specifically designed for LED control, also makes programming complex lighting effects easier. Beyond its technical capabilities, the Arduino Uno benefits from a large and active community, offering many resources and tutorials. The Arduino Uno is the most used and documented board in the Arduino family. Other Arduino boards, like the Arduino Mega and the Arduino Micro, would also be good options. Using the Mega would reduce the system's compactness, but it would be beneficial if the number of LEDs were increased beyond what is used in the described setup, as it has more SRAM space than the Uno.

3.1.1.2 LED Strip

WS2812B LED strips offer integrated control circuitry and RGB LEDs, allowing individual pixel control with just one data line. This feature simplifies wiring and programming, making it possible to create complex lighting effects and color transitions with minimal hardware complexity. Moreover, the WS2812B's ability to be cut to any desired length offers flexibility in design. Each pixel in the strip can display 256 brightness levels for each of the three primary colors (red, green, and blue). This capability allows the pixel to combine these colors in various ways, producing a full spectrum of 16777216 colors. Its high brightness levels, wide color spectrum, and ease of implementation made it a good choice for this work. Other versions of the WS2812B IP-64, such as the IP-65 and IP-67, come with waterproof covering and are both good alternatives. The IP-64 was preferred for this work as it was easy to access.

3.1.1.3 Inertial measurement unit

The MPU6050 IMU is selected for its precision and versatility. This sensor combines a 3-axis gyroscope and a 3-axis accelerometer on a single chip, providing spatial movement and orientation data. The integration of these two sensors allows for detailed and accurate tracking of both linear acceleration and angular velocity. Utilizing the I2C communication protocol, the MPU6050 is easily interfaced with the Arduino Uno, facilitating straightforward data acquisition and processing. Libraries such as the I2C device library[34] significantly simplify the task of programming the MPU6050. The MPU6050's low power consumption and compact form factor further contribute to its suitability for this specific project, where small sizes allow for placing all components in small cases and creating a setup that is comfortable to wear for the skier.

3.1.1.4 Circuit Setup

The LEDs are powered by a power supply through a breadboard power supply module. This module serves as a bridge between the USB-A output of the power supply and the LED strip's 5V input. It is also used as a reference ground for both the LEDs and the Arduino. The Arduino is powered by the power supply directly using a USB-A to USB-B cable. Figure 5 shows a diagram for the setup and connections between the Arduino, LED strips, IMU, power supply module, and power supply. Pull-up resistors are employed to ensure stable and reliable communication over the IMU's I2C bus by maintaining defined logic levels on the data and clock lines. The LED strips have three inputs each: the power, ground, and data input. The power supply module and IMU are placed on separate breadboards in the actual implementation.

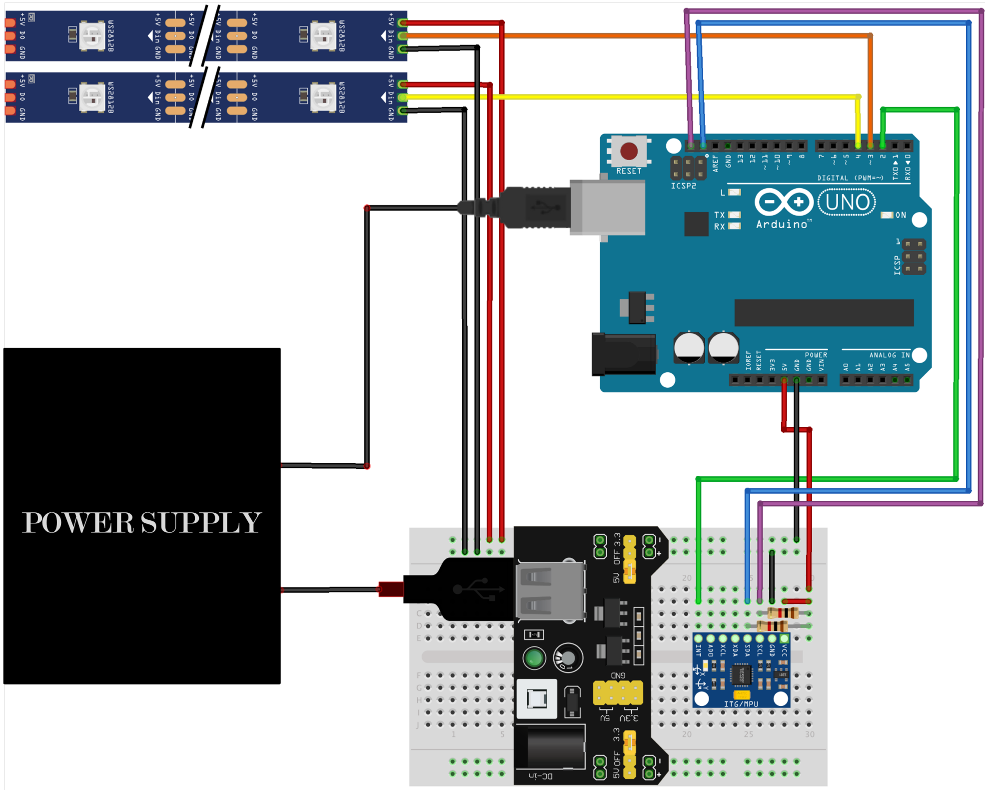
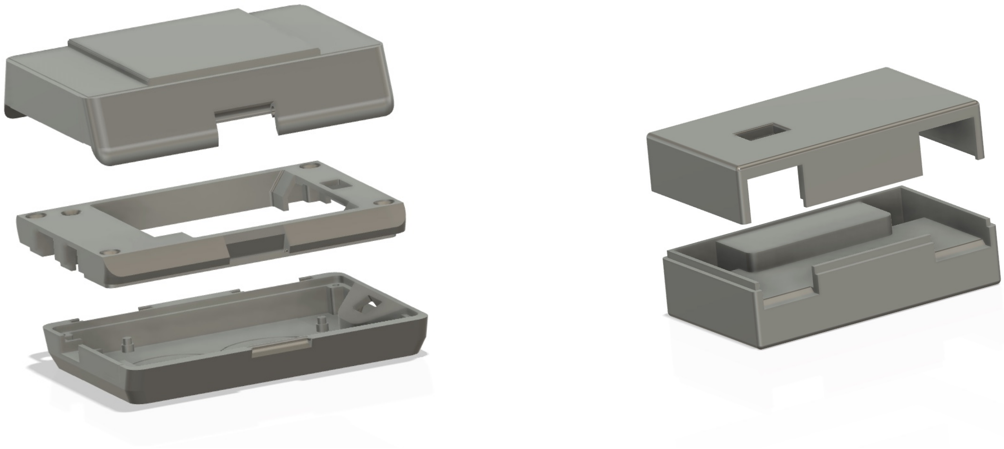


Figure 5: LED system circuit. This image was created with Fritzing [35].

3.1.1.5 3D Printed Cases

To make the system more robust, protective cases are designed and 3D printed. Figure 6a shows the 3D model of a case for the Arduino, IMU, and their wiring, and Figure 6b is a case used for the power supply module. The cases are designed to fit snugly with the selected components to maintain the system's compactness. The cases are printed in polylactic acid (PLA), an eco-friendly, biodegradable polymer. PLA, as one of the leading alternatives to petroleum-derived plastics due to its environmental benefits [36], supports the UN's SDG 12 for responsible consumption and production.

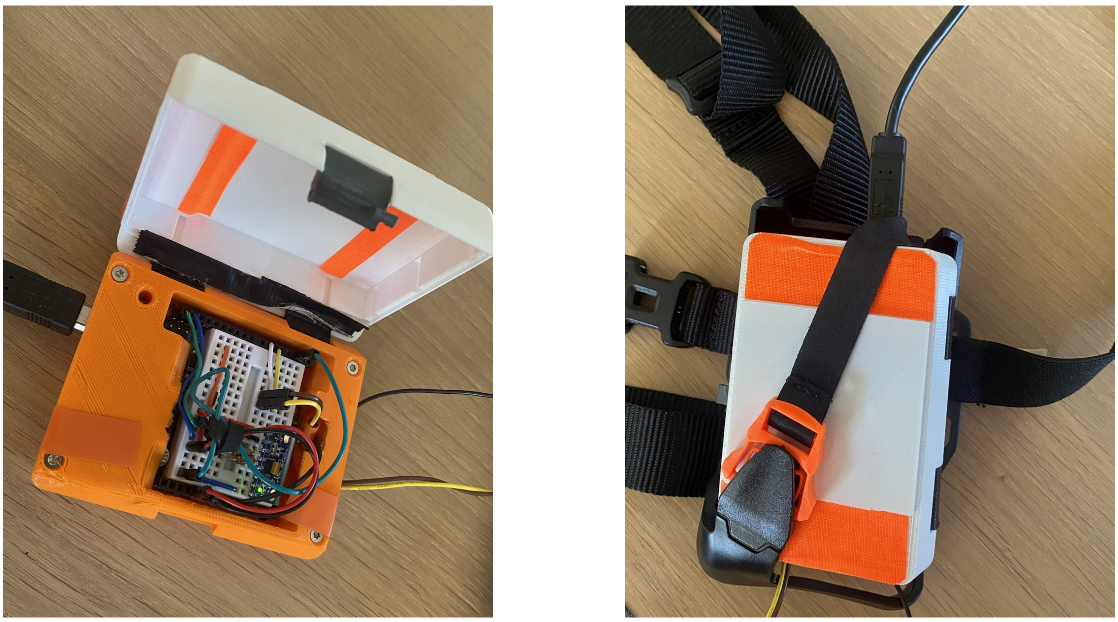
Figure 7a shows the case for the Arduino and IMU with an open lid, and Figure 7b shows the same case placed in the avalanche beacon strap that serves as the mounting mechanism when attaching the case to a skier. A small breadboard is placed between the Arduino pins. One side of this breadboard contains the MPU6050 and its connective wires. The other side is left empty, with room to integrate a memory card module for possible future development. In addition to the USB cable that powers the Arduino, three wires can be seen on the right side of the case in



(a) Case for Arduino and IMU. **(b)** Case for power supply module.

Figure 6: Models for protective casings.

Figure 7a. This is the reference ground from the power supply module (black wire) and the wires used to transfer data to the LED strips (brown and yellow wires).



(a) Printed case for Arduino and IMU with open lid. **(b)** Printed case for Arduino and IMU with mounting strap.

Figure 7: The protective case used for the IMU and Arduino.

3.1.1.6 Mounting and Integration on the Skier

Two separate avalanche beacon straps attach the LED system to the skier—one for the power supply and one for the case with the Arduino and IMU. In addition, a reinforcing cable is taped underneath the LEDs to improve their robustness. This cable is attached to Velcro straps, which keep the LED strips in place along the skier's arms.

Figure 8 is a picture that shows what the LED system looks like when worn by a skier. The skier's jacket covers the power supply, sensor, and microcontroller board so that only the LED strips are visible.

Figure 8: LED system mounted on skier. The LED strips stretch from the shoulders to the wrists, and the rest of the system is covered by the skier's jacket.

3.1.2 LED Algorithm

3.1.2.1 Attitude and Heading Reference System

An Attitude and Heading Reference System (AHRS) is a sensor setup designed to provide accurate information about an object's orientation and heading relative to the Earth's surface. Utilizing a combination of accelerometers, gyroscopes, and sometimes magnetometers, an AHRS can determine the pitch, roll, and yaw of an object in real-time [37]. Unlike traditional gyroscopic navigation systems, an AHRS uses advanced algorithms and sensor fusion techniques to compensate for drift and to provide a more reliable and accurate measurement of orientation. In this work, the code for forming a simplified AHRS and using the IMU data to control LEDs is heavily influenced by [38], which utilizes the I2C device library found in [34] for the interface between an Arduino and an MPU6050. The code utilizes the MPU6050's onboard digital motion processor (DMP) and six degrees of freedom to estimate the pitch, yaw, and roll.

3.1.2.2 Color Mapping

The LEDs are colored based on the degree of rotation around the yaw axis, which is calculated using the AHRS. When the skier goes straight, the pixels are green. The color turns towards blue or red based on whether the skier is going right or left. This effect is obtained by individually computing the R, G, and B values of the RGB color. The G value is calculated by setting it to the maximum 255 for 0° and 180° rotations and linearly decreasing it if the measured yaw is far from these extremes. Similarly, the R and B value have their respective maximums for -90° and 90° yaw rotations and lower values when moving away from these levels of rotation. Figure 9 illustrates how a given rotation is mapped to a color.

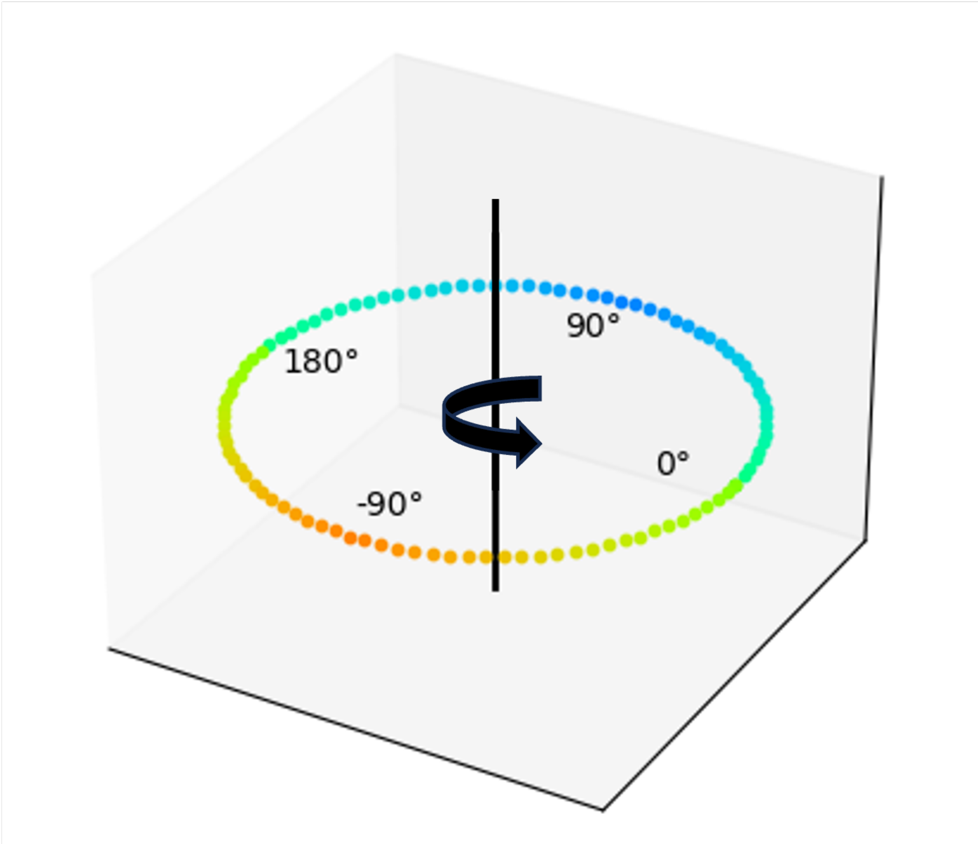


Figure 9: Mapping from yaw rotation in degrees to color.

3.1.2.3 Fade Effect

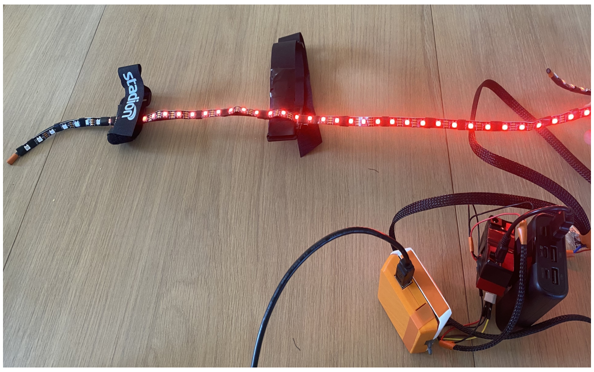
A fading effect adds a layer to the visual effect created by the LEDs and creates a visual illusion of the skier pushing the color to one side while turning. This reduces the brightness of pixels that are opposite to the skier's direction. If the skier turns right, the LEDs on his left arm will gradually dim as his rotation increases, and the LEDs on the right side will dim if the skier turns left. To implement this, one of the pixels is chosen as the *Directional Index*, which is calculated using the following equation:

$$DirectionalIndex = \frac{numPixels \cdot yaw}{360} \tag{1}$$

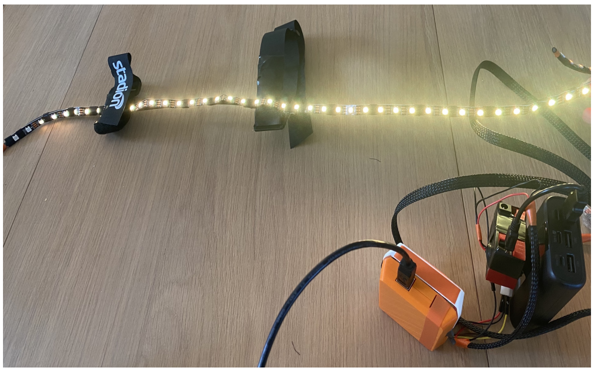
where $numPixels$ is the total number of pixels per LED strip, and yaw is the yaw rotation in degrees. The *Directional Index* is initialized to be a pixel close to the skier's chest and will move right when the skier moves right and vice versa. The brightness is adjusted by scaling the R, G, and B values of each pixel based on its distance from the *Directional Index*. This distance equals the number of pixels between a given node and the node of the *Directional Index*. The brightness has a maximum value of 255 and is calculated using the following equation:

$$Brightness = 255 - brightnessFactor \cdot distance \tag{2}$$

The $brightnessFactor$ is a constant set based on trial and error. Figure 10 show how the brightness of the pixels change as the IMU is rotated. In Figure 10a, the leftmost pixels are completely faded, and the brightness gradually increases for pixels further to the right. In Figure 10b and Figure 10c, the IMU is rotated, and it can be seen how, in addition to the change in color, the brightness is increased for pixels on the left.



(a) LED strip with leftmost pixels completely faded.



(b) LED strip with little fade.

(c) LED strip with no fade.

Figure 10: Color and fade changes as the IMU is rotated.

3.2 Detection

To detect the skier in the video and then add visual effects based on the skier's position, a YOLOv8 [39] detection model is used. The You Only Look Once (YOLO) series of deep learning models for real-time object detection stands out for their exceptional speed and accuracy in detecting objects across various conditions and backgrounds [9]. At the time of this work, YOLOv8 was the latest and most advanced iteration, offering improved performance and efficiency compared to its predecessors [12]. Although YOLOv8's strength of real-time detection is not utilized in this work, the model's quick and accurate processing of videos without the need for large amounts of computational resources makes it a good option. YOLO models work by dividing each video frame into a grid and predicting bounding boxes and probabilities for each grid cell. The models apply a single neural network to the full image, making predictions directly from full images and outputting bounding box coordinates.

3.2.1 Custom Model

Pretrained YOLOv8 object detection models are available, but to obtain a model that is adjusted for only detecting skiers, a custom model is trained using a dataset of images of skiers. This model is trained using data from [10], which consists of 352978 frames from single- and multi-camera videos of alpine skiing, freestyle, and ski jumping athletes. The dataset is reduced to a set of 1200 individual images from alpine and freestyle skiing to reduce training and annotation time. Images from ski jumping are not used as this discipline is considered less relevant and similar to freeskiing. The images used to train the model are manually annotated with the two classes *Skier* and *Ski*. The purpose of training the model to detect not only the skier but also the skis is to place effects based on the position of the skis more accurately. The detection of skis is not utilized for the placement of effects in this work but could be useful in further development.

The annotated images are saved in the YOLO format, which uses a single *.txt* file for each image with one row per object in the image in the format *class x_center y_center width height*. The 1200 images from [10] are divided based on the following split: 840 for training, 200 for validation, and 160 for testing. Rotation, brightness adjustments, and noise additions are used to increase the size of the training set, and three outputs are created per original image. This results in 2520 training images and a total dataset of 2880 images.

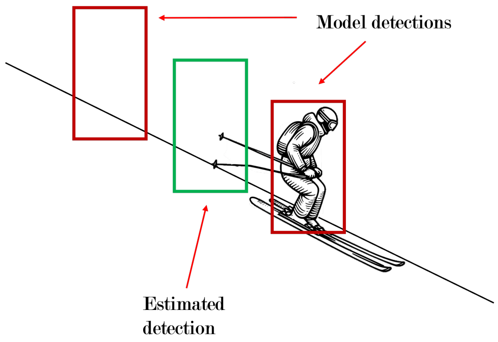
A popular pretrained YOLOv8m model is trained on the COCO dataset [40], which has about 200 000 images with annotations for object detection and 80 different categories of objects. Although this broad training base enables YOLOv8m to perform well in varied and unpredictable environments, the custom model, specifically trained to detect objects categorized as *Skier* and *Ski*, could potentially outperform the pretrained model in specific scenarios related to skiing. This specialized focus allows the custom model to be highly tuned for the details of skiers' appearances, such as posture, equipment, and attire. The images used to train the custom model are under snowy and dynamic conditions that might be underrepresented in the COCO dataset. Training on a smaller, highly specialized dataset means the model may better discriminate between relevant and irrelevant details in contexts filled with snow, ski equipment, and winter sports attire, reducing false positives and improving detection precision in ski-related environments. This specialization can lead to higher performance metrics in its niche application, despite the smaller size of its training dataset, by focusing its learning capacity on a much narrower task. A custom model significantly reduces class confusion by focusing on fewer, more relevant categories, which improves class discrimination. This is particularly advantageous in scenarios where accurate differentiation between similar object types directly impacts performance, such as distinguishing between various skiing disciplines. In this work, the pretrained YOLOv8m model trained on the COCO dataset is used as the benchmark when evaluating the performance of the model trained on a custom dataset.

3.2.2 Detection in Reduced Lighting

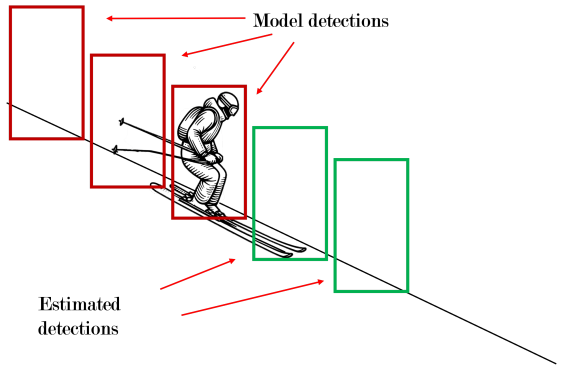
Dark environments can improve the visual effect created by the LED system because the dynamic colors become more noticeable, and the LEDs can color the surroundings. However, when using a detection model on videos recorded in environments with little light, the number of detections can be significantly reduced because the skier blends into the background, unlike in well-lit daylight conditions. To increase the amount of data and prevent gaps in the positioning of effects in Unity, both interpolation and extrapolation techniques are used. These methods estimate the missing data and extend the sequence of detected objects beyond the last observed point.

After generating bounding box coordinates and timestamps for each of the detections from the detection model, interpolation is applied to generate intermediate detection data when consecutive detections are separated by more than a frame. This is done by calculating intermediate coordinates and timestamps between known detections. This fills in gaps and provides a smoother sequence of detected objects across frames.

Extrapolation is then used to extend detection data beyond the last known detection up to the video's final frame. This process is useful when the video continues beyond the last detected object and the skier moves in a previously established direction. Calculating the average change in coordinates between detections and applying these changes incrementally predicts where the skier will appear in subsequent frames.



(a) Interpolating bounding box data to estimate intermediate detections.



(b) Extrapolating bounding box data to estimate subsequent detections.

Figure 11: Interpolation and extrapolation. These images were created with the assistance of the image generator DALL-E 2.

3.2.3 Color Extraction

After running the detection model on a video, an algorithm for extracting the dominant color within the area defined by each bounding box is used. The purpose of this is to obtain information about the color of the LEDs at any given time, which can be used to make the particles in Unity's particle systems match the LED colors. Finding the dominant color is done by processing each frame in the video and aligning it with the coordinates from the detection model. The colorthief library [41] is utilized to identify the dominant RGB color in the bounding box area. As seen in Figure 12, which shows a bounding box around a skier with light blue LEDs on his arms, the recorded videos are typically dominated by black or dark gray backgrounds. A filtering function that only considers brighter colors is used to suppress these darker colors. This is done assuming that the LED system will be used when there is little daylight or external lighting. As a final step, the extracted and filtered color is translated to HSV (Hue, Saturation, and Value), and the value is increased to enhance the bright color. The resulting color is stored as an RGB value alongside their corresponding bounding box data.

Figure 12: Detected skier in dark surroundings.

3.2.4 Keypoint Extraction

To properly adjust the post-editing effects based on the skier's movements, it is necessary to have information about the skier's placement and the turning from side to side. A pose estimation model identifies and tracks specific anatomical landmarks or keypoints on the skier's body, such as joints and limbs. Figure 13 shows the keypoint output of such a model, where arms, torso, head, and arms are identified. This information can be used to estimate the angle of the skier relative to the ground. Assuming that the skier's upper body is leaning towards the direction of the turn, which is typically the case when skiing downhill, it is possible to approximate when the skier turns left or right. A pre-trained YOLO pose estimation model is used to extract the keypoints. This model extends the basic object detection framework to detect objects and predict the pose of one or more objects. The preferred model in this work is the YOLOv8m pose model. This is a YOLOv8 model trained on a subset of the COCO dataset called COCO-Pose, which focuses on human pose estimation. Figure 13 illustrates the output from this model.

Achieving optimal results with a pose estimation model depends on ensuring proper lighting, object visibility, and sufficient image quality [42][43]. The subject must be fully visible and stand against a simple background to avoid confusion with the surroundings. To capture detailed and stable images, it is important to have a suitable camera with appropriate quality, resolution, and focus. Additionally, the positioning of the camera, including the distance and angle, should be

Figure 13: Keypoints and bounding box predicted by a pose estimation model.

optimal to ensure that all relevant keypoints are within the frame and clearly detectable. These conditions ensure the precision and reliability of pose estimation in varied environments. In ski videos, the above requirements are often met when recordings are made in daylight, as the skier typically stands out from a white background and body features are distinguishable. However, the system presented in this work is likely to be used in settings with little natural light. This can introduce limitations to using keypoint extraction for estimating the skier's angle.

In this work, two different models are used for detection and pose estimation due to the distinct challenges of each task. The detection model is trained on a custom dataset tailored specifically for identifying elements in ski videos, unlike the pretrained model that detects objects across 80 different categories. On the other hand, pretrained pose models are typically developed from extensive and varied datasets specializing in human pose recognition. These models are designed to capture detailed aspects of human posture and movement, making them exceptionally effective and precise across different situations, including skiing. Developing a custom pose model to match the performance of the pretrained model would be difficult, given the complexity of its training process. Although the pose estimation model is also capable of object detection, it does not surpass the detection capabilities of the more specialized object detection model. The object detection model may still identify skiers in challenging filming conditions with low light, where pose estimation may fail due to reduced visibility. In this scenario, bounding box coordinates are collected even if detailed pose analysis is unavailable.

4 Method

4.1 Unity

Unity is primarily recognized for its game development capabilities but is customized in this work to be used for video editing. 3D content can be integrated into videos by projecting a video onto a canvas within a 3D space. Objects and effects can be added between the canvas and a virtual camera before rendering. Figure 14 illustrates the described setup of a camera pointed at a canvas with a game object in between. In this project, Unity facilitates the incorporation of dynamic particle effects into ski videos.

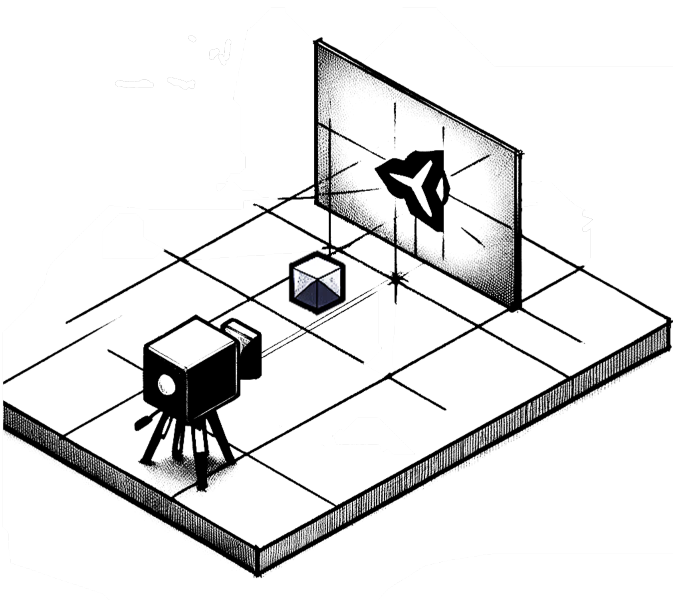


Figure 14: The setup in a Unity 3D space, consisting of a camera, canvas, and an object (represented by a small cube) that adds an effect to the video. This image was created with the assistance of the image generator DALL-E 2.

4.1.1 Project Setup

The workflow in Unity used in this work is illustrated in Figure 15. The process begins with the input of video files along with the associated bounding box and pose estimation data. The video is managed within Unity using the *Timeline* feature, which is used to organize the video sequences. In the diagram, a dotted line symbolizes that the timeline synchronizes the effects. The bounding box data and keypoints are managed within a video object, which uses the data to place a cube object. The cube is used as a reference point for positioning particle effects. Scripts are attached to this cube object to dynamically adjust the movement and color of particle systems based on analyzed video data. Unity's recording tool is employed to capture the final output, which includes the original video enhanced with synchronized particle effects. The Unity project, including the placement, movement, and color scripts, can be found here: https://github.com/simendo/unity_freeride.

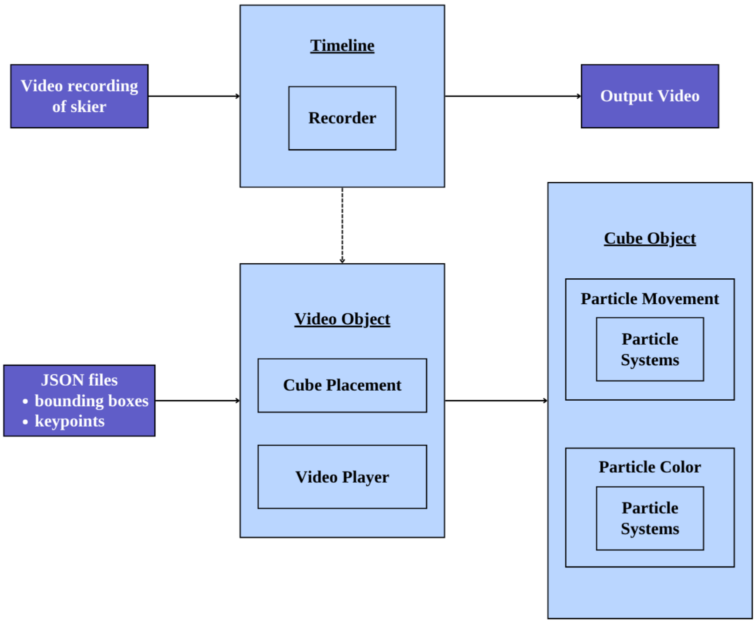


Figure 15: Diagram illustrating the workflow in Unity.

4.1.2 Object Detection in Unity

Inference libraries such as *Barracuda* [7] enable the use of detection models directly within Unity at runtime. This integration streamlines the development process by maintaining all operations within a single platform. Performing object detection directly in Unity also eliminates the need to synchronize detections with specific timestamps, simplifying real-time applications. Although *Barracuda* has shown promising results in applications such as those documented in [8], it has certain limitations. The library primarily supports smaller architectures, such as

Tiny YOLOv2, and challenges have been observed when trying to integrate custom detection models. Additionally, from experimenting with the library, it was found that its use in video object detection can introduce significant latencies, affecting the real-time performance within Unity. Because of these sub-optimal characteristics, *Barracuda* is not used in this work. Instead, object detection is executed outside of Unity, using the custom model described in Section 3.2, before parsing a file containing data from the model output in Unity.

4.1.3 Parsing Data

JSON files are used to utilize the data found from the methods described in Section 3.2 in Unity. For a given video, one JSON file contains the corresponding data from the detection model and extracted color in the following format:

$$timestamp : time, coordinates : [xMin, yMin, xMax, yMax], class\_id : [], class\_name : [], color : [r, g, b]$$

where $time$ is the time in the video that the data belongs to, $xMin, yMin, xMax$, and $yMax$ are the minimum and maximum x and y values of the corners that make up the bounding box, $class\_id$ and $class\_name$ contain the name and id for the detected object, and r, g and b are the RGB values of the extracted color.

A separate JSON contains the pose estimation data formatted as:

$$timestamp : time, keypoints : [keypoint\_0, ..., keypoint\_16]$$

where $keypoint\_0$ to $keypoint\_16$ includes the x and y values for the 17 keypoints from the pose estimation model.

4.1.4 Particle Systems

Using Unity's powerful Particle System, detailed and dynamic snow spray effects that respond to the skier's movements and interaction with the virtual environment are created. This includes mimicking the dispersal patterns of snow as it's kicked up by the skier's movements and turning through the snow. When added to a video recorded at night, this artificial snow spray effectively replaces the natural snow spray, which is typically not visible due to insufficient lighting. Several particle systems are combined to make the particles look and behave more like the relatively complex motion and composition of actual snow. This includes using a smoke-like particle cloud with additional smaller snow particles inside it. Additionally, a separate particle system with adjustments such as increased particle lifetime is designed for videos recorded from a static camera angle. Figure 16 shows a screenshot from a Unity project where a particle system is placed in front of a canvas to add a snow spray effect, similar to the general setup illustrated in Figure 14.

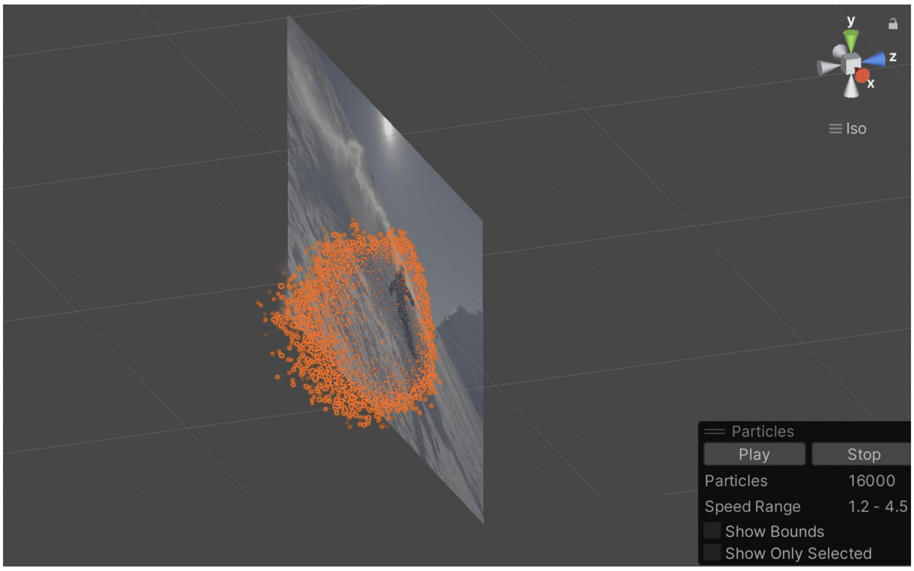


Figure 16: Canvas with video and particle system placed in front.

4.1.4.1 Particle Placement

To accurately place the particle systems based on the skier's position, the bounding box coordinates found by the detection model are used. The positioning data is parsed into a *BoundingBox* class, and a cube object is placed at the given coordinates. The particle systems are then placed relative to this cube.

When keypoints from the pose estimation model are available, an estimate of the skier's angle θ with respect to vertical can be calculated by creating a vector from the hip to the toe on each side and taking the cross product with a vertical vector. The vectors, keypoints, and θ are illustrated in Figure 17, and the calculation is described in depth below.

Figure 17: Skier with keypoints and vectors used for calculating angle with respect to vertical.

Given two keypoints representing the hip and the foot, **hip** $= (hip_x, hip_y)$ and **foot** $= (foot_x, foot_y)$, the vector from hip to foot is defined as:

$$\overrightarrow{hipToFoot} = \mathbf{foot} - \mathbf{hip} = [foot_x - hip_x, foot_y - hip_y]$$

The vertical vector pointing upwards along the y-axis is:

$$\overrightarrow{vertical} = [0, 1]$$

The angle in radians $\theta_{radians}$ between the vertical vector and the normalized vector $\overrightarrow{hipToFoot_{norm}}$ is calculated using the arccosine of the dot product:

$$\theta_{radians} = \cos^{-1}(\overrightarrow{vertical} \cdot \overrightarrow{hipToFoot_{norm}})$$

This angle is converted to degrees, and if $hip_x > foot_x$, the angle is considered negative:

$$\theta_{degrees} = \begin{cases} \theta_{degrees} & \text{if } hip_x \leq foot_x \\ -\theta_{degrees} & \text{if } hip_x > foot_x \end{cases}$$

The skier's direction is then estimated based on the average value θ_{avg} of $\theta_{degrees}$ for the left and right leg, and the current direction is set to one of five alternatives:

Average Angle	**Skier Direction State**
$-8 \leq \theta_{avg} \leq 8$	Straight
$8 < \theta_{avg} \leq 20$	Soft Left
$-20 \leq \theta_{avg} < -8$	Soft Right
$\theta_{avg} > 40$	Hard Left
$\theta_{avg} < -20$	Hard Right

Table 2: Skier direction estimation based on average angle θ_{avg}.

The calculations provide a very rough estimate using a simple approach, but this can be sufficient as the purpose of determining the direction is to place the particle effects on the side that is opposite to where the skier is turning. The difference between *Soft Left* and *Hard Left*, and equally for *Soft Right* and *Hard Right*, is used to give the particles increased velocity and an output angle that points more away from the skier when sharp turns are detected. In these cases, the skier direction state is set as *Hard Left* or *Hard Right*.

4.1.4.2 Particle Movement

The particle systems' parameters are adjusted to reflect the sense of randomness and variability of natural snow. The general parameters include parameters such as speed, rotation, and lifetime. Varying the speed and rotation parameters can mimic the swirling of snowflakes. Adjusting the particle lifetime determines how long snow remains visible after being disturbed. Additionally, a force field is added to influence the trajectory of the particles. A force field can simulate the wind or work as a gravitational field. To make the particles be thrown up in the air by the skier's carving before slowly falling to the ground, the force field is used in combination with Unity's *gravity over time*, which allows for adjusting the gravitational pull on the particles over their lifetime.

Dynamic adjustments to the emitting volume directly influence particles' initial direction and spread. The emission shape used in this work is a cone that varies its radius and length depending on the height of the bounding box surrounding the skier. Figure 18 illustrates these adjustments. In Figure 18a, the detection of the skier has resulted in a smaller bounding box compared to in Figure 18c. As a result, the emission cone, which can be seen as a light blue object, appears proportionately smaller in the first image. Figure 18a and Figure 18b show the same moment from both a front and a side view for better visual understanding. The orange fields in the images surround the active particles emitted from the particle system.

(a) Small emission volume. **(b)** Side view of small emission volume. **(c)** Larger emission volume.

Figure 18: Screenshots from Unity showing the cone-like emission volume used for the particle systems.

4.1.4.3 Particle Colors

When the color of the LEDs is extracted using the method described in Section 3.2.3, this color can be used in Unity and added to particles. Each color is tied to a specific timestamp, allowing the particle colors to change in sync with the LED colors. This links the skier's and snow's colors and adds to the visual effect already created by the LEDs.

To provide an alternative to using the extracted color, logic for using predefined colors that are adjusted based on the detected skier direction is also designed. This approach can be used to adjust the particle colors such that the coloring mirrors the detected direction in a similar manner to the color mapping described in Section 3.1.2.2. In the Unity inspector, a default color can be selected. This color is used if neither the direction nor the extracted color is available.

Unity's *color over lifetime* allows changing the colors assigned to particles during their lifetime. This module is used to adjust the particles' alpha value, or transparency, to make the particles fade in when they are generated and fade out after some time.

4.2 Evaluation Methods

Evaluating the quality and effectiveness of any new technology or methodology requires robust evaluation strategies. To evaluate the system designed in this work, quantitative and qualitative data were gathered to assess how well it met its intended goals and users' needs. Quantitative data provides statistical evidence of performance metrics, which can be used to quantify attitudes or opinions. While quantitative data can give numerical feedback, qualitative data can offer deeper insights into user experiences. It can be collected using methods such as interviews, expert opinions, case studies, or surveys. Integrating both data types in the evaluation process makes it possible to provide a fuller picture of the evaluated system's impact.

This work utilizes both an in-depth interview and a survey to gather qualitative and quantitative evaluations of the LED system and post-production effects. The in-depth interview aims to capture detailed perspectives on the LED system's potential as a tool in ski video production. The survey, which was conducted as an online questionnaire, includes multiple-choice questions where participants can respond quantitatively based on their impressions. As presented in [44], online surveys can also be a good source for qualitative data, and participants tend to give more informative and longer answers compared to when paper surveys are used. Free-text answers are added in addition to the multiple-choice questions to include the collection of qualitative data from the online survey.

4.2.1 In-Depth Interview

The primary goal of the interview was to understand the potential impact of including the LED system in ski video production and to gather firsthand feedback on the need for improvements. The participants were Dennis Risvoll and Kaja Vik from the film production company Frys Film. They were selected based on their expertise and experience in ski filmmaking and skiing. Dennis Risvoll is an experienced freeskier who has worked both in front of and behind the camera. He has participated in various ski film productions and produced content for his channels for the last 15 years. His special interest in technical gadgets and action-packed outdoor productions provides a unique perspective on how new technologies can improve visual storytelling in ski filmmaking. Kaja Vik has an academic and professional background in media production and a good understanding of media production's theoretical and practical aspects.

Some of the in-depth interview tips presented in [27] were utilized when planning and conducting the interview. This included using follow-up questions during the interview to probe for more information and being conscious about the choice of question words. After inspecting the system and observing a skier who used it, the participants were given questions regarding the quality of the LED system's hardware and the visual effect created by it. They were also asked about the system's innovativeness and what changes would be needed before using it in a full-scale ski film production.

4.2.2 Ski Video Feedback

A questionnaire was created to collect feedback from individuals without any association with the project. A stated preference approach was utilized to select participants, specifically targeting people interested in skiing. This method ensured that the feedback and insights gathered were directly relevant to the experiences of people engaged in the skiing community. This audience is considered a more likely target for ski film productions. To obtain replies from people who were already familiar with freeskiing, responses to the questionnaire were collected from *NTNUI Topptur and Freeride*, which is a group used by students at the Norwegian University of Science and Technology (NTNU) to organize freeskiing trips or ski-related events. In addition to targeting participants with a stated preference, the questionnaire included individuals less familiar with freeskiing. This inclusion aimed to capture a broader spectrum of perspectives and better understand how opinions differ between groups. The majority of respondents were students at NTNU. The questionnaire can be found in Appendix A.1.

5 Verification and Validation

The evaluation process consisted of the following parts:

- **LED System Functional Verification**
  Focused on direct testing of the LED system's performance and functionality.
- **Detection Model Verification**
  Verified custom model accuracy and compared it to a pretrained model.
- **Field Testing of LED System and Video Documentation**
  Covered the practical testing of the LED system in a real-world skiing environment and the recording of these tests for further analysis and post-editing.
- **Interview**
  After field testing, an interview was conducted to get feedback from film company personnel who participated in or observed the field testing and recording sessions.
- **Feedback Analysis through Questionnaire**
  The collection of feedback from viewers of edited video recordings from field testing, using a questionnaire to assess viewer impressions and satisfaction.

5.1 LED System Functional Verification

Table 3 and Table 4 describe requirements that are set for the LED system based on the desired functionality. The numbers used for the temperature requirements are based on the assumption that the system will be used outside at temperatures close to 0°C, but it should also be functional for colder temperatures down to -20°C. To ensure smooth color changes, the time for LED color updates in response to the skier's movements should be faster than the flicker fusion threshold [45], which is approximately $50Hz$, or $20ms$. This rapid update rate will make the color transitions appear continuous, aligning with natural human vision capabilities.

5.1.1 LED System Requirements

Req. No	**Requirement**
1.1	Repeating a given rotation to the IMU results in the same pixel color.
1.2	Color of LEDs changes within $20ms$ after the skier's movement.
1.3	The system's brightness is sufficient to produce a noticeable visual effect when captured on video.

Table 3: Functional and performance requirements for LED system.

Req. No.	**Requirement**
2.1	The system can handle temperatures between -20 and 25°C.
2.2	The system's battery life is more than 4 hours when used outdoors at 0°C.
2.3	The system can be worn while skiing without limiting the skier's movements.

Table 4: Environmental requirements for LED system.

5.1.2 LED System Tests

Requirements 1.1, 1.2, 2.1, and 2.2 are tested in laboratory tests, while requirements 1.3 and 2.3 are tested during the field testing presented in Section 5.3. Table 5 describes the tests that are conducted to verify the requirements found in Table 3 and Table 4.

Req. No	Description of Test
1.1	The requirement is tested by rotating the system and documenting the perceived color after each 90°rotation. This is done for 5 full rotations (360°) before resetting the system and completing another 5 full rotations.
1.2	The requirement is tested by analyzing the program code to see how often the IMU data is reevaluated and used to color the LEDs.
1.3	Feedback from personnel from a ski film production company determines whether the brightness is high enough and the requirement is met.
2.1	The datasheet of the system's components is used to find the minimum and maximum temperatures. It is assumed that if all components can handle temperatures in the range specified by the requirements, the system as a whole is also functional for these temperatures.
2.2	The requirement is tested by measuring the power usage of the LEDs at full brightness and calculating the expected lifetime based on the capacity of the power supply and the power supply module. The requirement is also tested by observing how much power is used during outdoor testing.
2.3	The requirement is tested by mounting the system on a skier who makes advanced ski movements such as 360-degree rotations. Feedback from the skier and observation of whether the LEDs are functional and respond to movement when being used for skiing is used to determine if the requirement is met.

Table 5: Description of tests for LED system.

5.2 Detection Model

To evaluate the accuracy of the custom YOLOv8 model and compare it to the performance of the pretrained model, the two models' predictions are compared to ground truth bounding boxes. The ground truths are created by manually annotating frames from two videos, one shot during the day and one at night. In the daylight video, the skier begins at a distance from the camera before gradually approaching and appearing larger. In the nighttime video, the skier is moving in a straight line from one side of the frame to the other. Although using only two videos gives a relatively small sample size, the evaluation can still provide a useful impression of how the models perform under different lighting conditions. For each image, objects are identified before the predicted bounding boxes are compared with the ground truth using the *Intersection over Union* (IoU) metric to evaluate the accuracy and calculate the number of correct predictions. The performance of each model is quantified by computing their accuracy rates based on the total number of correct detections relative to the ground truth. The precision, recall, and F1 scores are calculated for both models. For additional comparison, the evaluation metrics described below are also calculated for the pose estimation model to test its object detection capabilities.

Precision measures the accuracy of positive predictions. It is the ratio of correct positive predictions (true positives) to the total predicted positives (the sum of true and false positives). Precision says how many detected objects were correct.

Recall assesses the model's ability to detect all relevant cases within the dataset. It is the ratio of correct positive predictions to the total actual positives (the sum of true positives and false negatives). High recall indicates that the model captures a large proportion of relevant objects. A high precision but low recall can happen if a model is too conservative in predicting the positive class, and the model misses many true positives but makes few false positives.

The F1 Score is a metric that combines both precision and recall to give a balanced view of the model's overall performance. The F1 score is calculated as follows:

$$F1 = 2 \times \left(\frac{\text{precision} \times \text{recall}}{\text{precision} + \text{recall}} \right)$$

5.3 Field Testing

Field tests were conducted to evaluate the system's functionality in real-world conditions, assess its potential, and identify areas for improvement. The tests involved mounting the LED system on an experienced skier who descended a piste multiple times under varying natural lighting conditions. Personnel from Frys Film, who possess expertise in ski film projects, directly handled the recording process. Feedback from the skier using the LED system and observations from reviewing the recorded videos were used to evaluate the system's performance. Figure 19a and Figure 19b show images taken during the field testing, where a skier who is wearing the LED system is pulled up a hill by a snowmobile before recordings start. The fade effect described in Section 3.1.2.3 was not tested during the field test. This decision was made because uploading new code to the Arduino would have taken valuable time, and it was considered more important to prioritize recording as many runs as possible.

(a) Skier being pulled by a snowmobile.

(b) Skier with LED strips on arms.

Figure 19: Images from field testing taken by Dennis Risvoll.

6 Results

6.1 LED System Laboratory Test Results

The following presents the results of laboratory tests, each identified by their corresponding test number as defined in Section 5.1.2.

1.1

To test the system's response to rotation, the color of the pixels is recorded after every 90°rotation as either red, green, blue, cyan, or orange. After 10 full rotations, there are no observed deviations in the color of the pixels from what is expected based on the color mapping described in Section 3.1.2.2. The test was repeated for the updated color mapping described in Section 7.1.3, which also provided satisfactory results as colors reacted to rotation as intended.

1.2

The yaw, pitch, and roll data is read once for every iteration of the main program loop. It is assumed that the time between these readings is the main cause of the potential delay between the skier's movement and a color change. Arduino's *millis()* function is used to record the time the program's main loop takes by subtracting an *endTime* timestamp from a *startTime* timestamp that is set at the end and beginning of the loop. The resolution of *millis()* is $1ms$, and for 300 iterations of the loop, the average time the loop takes to execute is $9.2ms$, with a minimum time of $8ms$, and maximum time of $11ms$.

2.1

Component	Min Temperature[°C]	Max Temperature[°C]
LED strip (WS2812)	-25	80
IMU (MPU6050)	-40	85
Arduino Uno	-40	85
Power bank	10	40

Table 6: Minimum and maximum temperatures for LED system components.

The temperature operating ranges for the components used in the LED system are presented in Table 6, as found in the components' respective datasheets. The LED strip, IMU, and microcontroller meet the requirements, but the power supply does not.

2.2

An ammeter was connected in series with a single LED strip of 44 pixels, all programmed to white color and full brightness. Both LED strips were connected to the power supply module during the test, but the current was only measured for one strip at a time to check for variations between the two strips. After testing both LED strips, the highest measured value for the current was $417.2mA$ for one strip. There was little variation in the current draw between the two strips. The maximum measured current gives a consumption per pixel of approximately $9.48mA$ and $834.4mA$ for the two strips. Figure 20 shows the setup for the test.

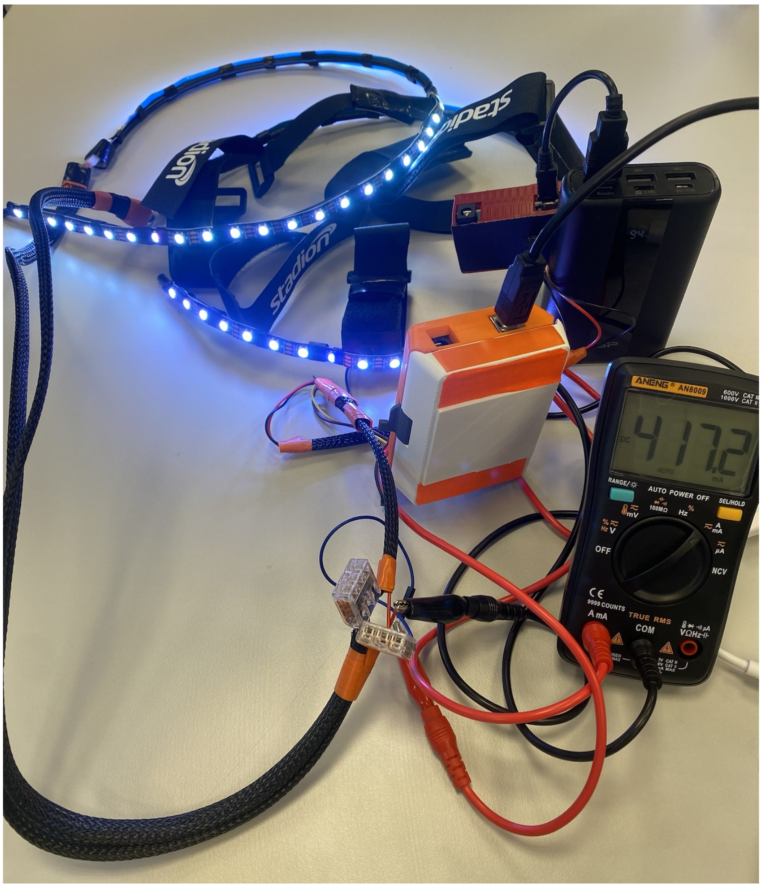


Figure 20: Measurement of current drawn by LED strips.

Power banks are typically rated based on their internal battery capacity at $3.7V$, but when outputting at $5V$, the effective capacity is reduced due to conversion losses [46]. As it is not specified in the datasheet for the Li-Polymer power supply used in this work [31], based on the findings in [46], it is assumed that there is an 85% efficiency when outputting at $5V$ instead of $3.7V$. The stated capacity of $20000mAh$ for the power supply is estimated to have an effective capacity given by

$$EffectiveCapacity = 20000mAh \times \frac{3.7V}{5.0V} \times 0.85 = 12850mAh$$

Based on results from [47], it is assumed that the Arduino Uno consumes an average of $125mA$ during operation. A current draw of $834.4mA$ for the two LED strips gives a theoretical runtime of

$$Runtime = \frac{12850mAh}{125mA + 834.4mA} = 13.39h$$

Although an official datasheet for the XD-42 power supply module could not be located, multiple sources indicate that its maximum output current is approximately $800mA$, a number that is close to the measurements obtained during testing. The power bank's datasheet shows it can output $3A$ at $5V$ when multiple outputs are connected.

6.2 Detection Model Evaluation

Figure 21 shows the predicted bounding boxes from the custom and pretrained detection models for a given frame from one of the videos used for evaluation, in addition to the ground truth.

Figure 22 shows the ground truth and the predicted bounding box for the custom model for a frame from a video recorded at night. This frame is from the second video used for the evaluation of the models.

Table 7 presents the performance metrics for the pretrained YOLOv8 object detection model, the YOLOv8 model trained on a custom dataset, and the pretrained YOLOv8 pose estimation model. The video used for evaluation was recorded in daylight and included 440 labeled bounding boxes, with no more than one bounding box per frame. As presented in Table 7, the pretrained model has many mispredictions. To understand if this is because of incorrect detections of other classes or if the predicted class is correct but the bounding boxes do not overlap the ground truth, the test is repeated, and the number of detections of other classes than *person* is counted. This test

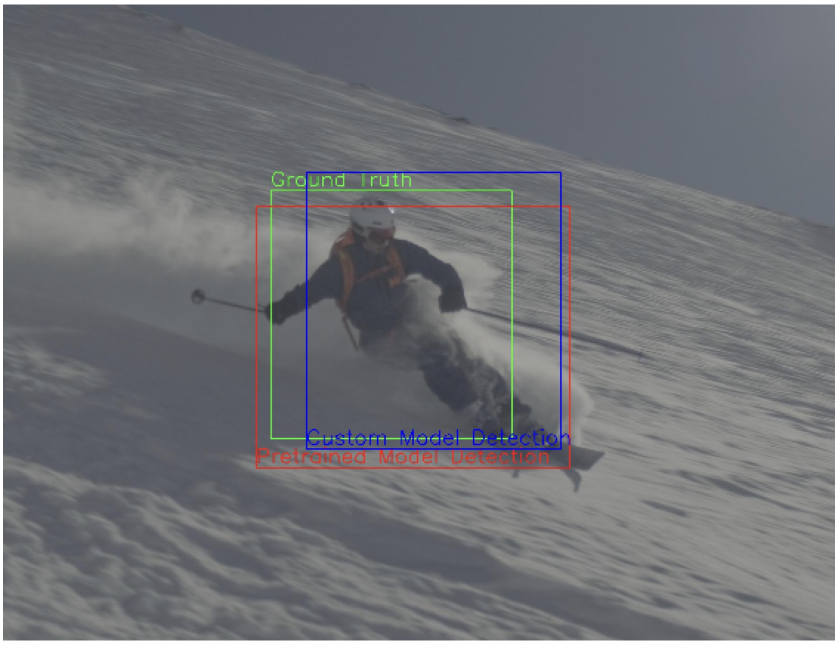


Figure 21: Bounding boxes from ground truth in green, the pretrained detection model in red, and the custom model in blue.

shows that out of the 441 incorrect predictions, 350 are from predictions of other classes, and 91 are from predictions of *person*. None of the 79 other classes that the pretrained model is trained on are present in the video used for evaluation.

Metric	Pretrained Model	Custom Model	Pose Estimation Model
Precision	0.37	0.78	0.93
Recall	0.60	0.44	0.46
F1 Score	0.46	0.56	0.62
Total Predictions	704	246	220
Correct Predictions	263	192	204

Table 7: Performance comparison of pretrained, custom, and pose estimation models for video shot in daylight.

Table 8 presents the performance metrics for the same models as above but for a video recorded at nighttime, including 103 labeled bounding boxes. All 15 predictions from the pretrained model were for other classes than *person*.

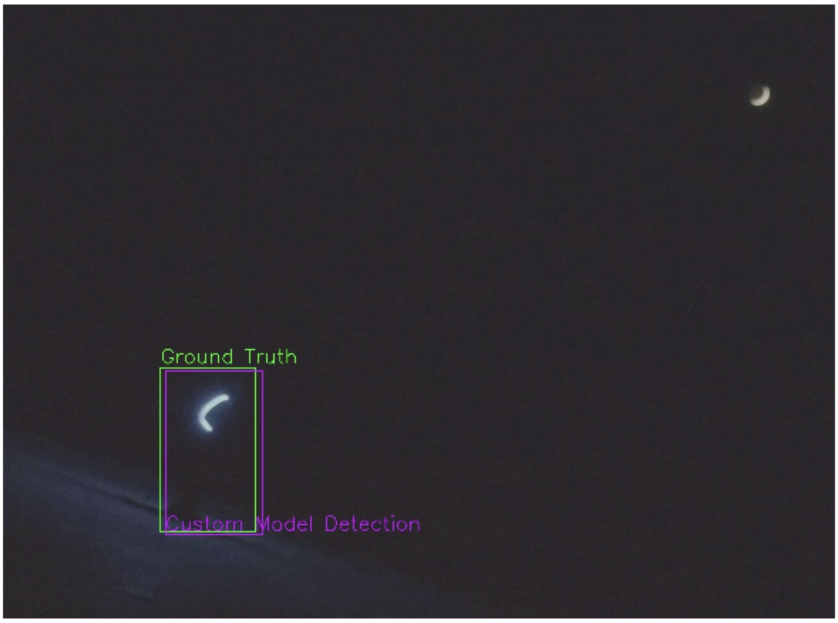


Figure 22: Bounding boxes from ground truth in green and the custom model in purple.

Metric	Pretrained Model	Custom Model	Pose Estimation Model
Precision	0.00	1.00	0.00
Recall	0.00	0.09	0.00
F1 Score	0.00	0.16	0.00
Total Predictions	15	9	0
Correct Predictions	0	9	0

Table 8: Performance comparison of pretrained, custom, and pose estimation models for video shot at nighttime.

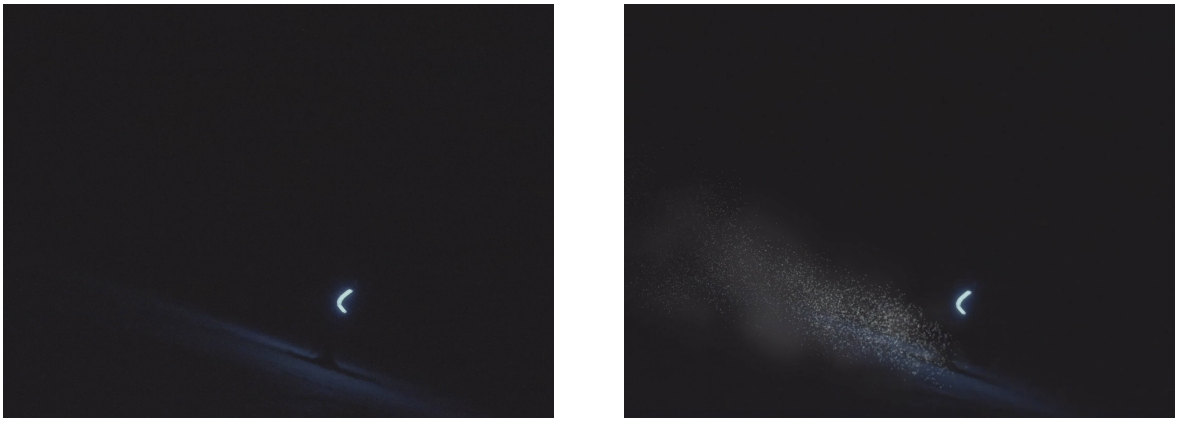
6.3 Field Test Results

6.3.1 Skier Feedback

Based on conversations with the skier during the testing, it was clear that the LED system did not limit the ability to perform advanced movements, such as jumps with 360° rotations. It should be emphasized that during the tests, electrical tape and rubber bands were used in addition to the LED system's mounting mechanisms to keep the system in place. However, once mounted, the system did not bother the skier. Based on this feedback, requirement 2.3 was considered fulfilled, but an improvement to the bands that hold the LED strips in place on the skier's arms would be needed for future development.

6.3.2 Field Test Recordings

Recordings from the field test were used to create a short video, which can be found here: `https://youtu.be/F8SjDWHWR2g`. This video features a series of clips captured from various camera angles and under different lighting conditions to demonstrate the LED system's capabilities. Some of the clips in the video were edited in Unity, where the particle effect described in Section 4.1.4 was used. Figure 23 shows a frame from a field test recording before and after editing in Unity. In the edited version in Figure 23b, one can see how two separate particle systems are used, as it includes a dim particle cloud with smaller particles inside it. This specific recording is shot using a static camera angle, and the skier moves from one side of the frame to the other. In these types of videos, where the skier is only moving in two dimensions, there is less need for dynamic adjustments of the particle system parameters as there is no need for depth adjustment. A static camera angle also allows for a longer particle lifetime because the position of previously emitted particles relative to the skier remains well-placed for a longer time.



(a) Single frame from field test recording. **(b)** Field test recording with particles added.

Figure 23: Images from field testing with and without post-editing.

In recordings shot from a distance at night time, the LED strips are clearly visible. However, the skier and the surrounding environment are hardly noticeable. The skier's outline and facial expression can be seen in close-up shots, as shown in Figure 24.

Figure 24: Close-up shot from field test.

6.3.3 Additional Observations

During the field testing, the system was used outdoors at temperatures ranging from about 4-7 °C for more than 4 hours. During this time, the battery percentage of the power bank decreased from 99% to 81%, and it was not registered any problems with the power supply.

It was observed that the initial threshold for rotations required to change the LEDs' color was too high. An immediate adjustment was made to the LED system's algorithm, resulting in a more responsive color change. The updated color mapping, which offered more satisfactory results, is detailed in Section 7.1.3.

6.4 Feedback From Interview

In the in-depth interview conducted with film industry professionals from Frys Film, several areas that needed improvement for the LED system to be used in filmmaking were identified. The following presents the main takeaways from the interview.

6.4.1 Feedback on Hardware

The interviewees noted that the mounting of the LEDs was too time-consuming and suggested integrating the system into a jacket for easier setup. Concerns were also raised about the durability of the power supply module, specifically the vulnerability of the USB input port. A redesign with a protective case was recommended to safeguard the connections and improve robustness. It was also suggested that relocating the power supply and battery pack to a backpack could reduce bulk around the abdomen, making it more comfortable for skiers to wear the system.

6.4.2 Feedback on Visual Effect From LEDs

It was desired that the system would recognize more complex movements, such as flips and jumps, which would allow a broader range of motion to be captured and visually displayed. Integrating sensors in ski boots was proposed as a way to enhance movement detection.

The relatively few LEDs provided a surprisingly high amount of light, even in brighter conditions, but their visual impact was notably greater at night. However, feedback suggested that even though the brightness from each individual pixel was sufficient, increasing the number of LEDs, especially on the legs, would improve the overall visual effects. In terms of system dynamics, the two interview participants agreed that adding variability in LED brightness based on the intensity of movements could enhance the visual representation of the skier's actions. This would include dimming or brightening the lights to create a more dynamic intensity.

Color responsiveness was another area of focus. It was emphasized that the need for highly responsive color was important, but maintaining consistent color outputs for specific angles did not have to be a priority for future development. It was highlighted that an adjustment to the responsiveness and color mapping of the LEDs that were made during the field test improved the visual effect.

Lastly, the dynamic nature of the LED lighting changes was highlighted as a highly innovative feature that distinguishes this system from other ski video productions, offering a unique and engaging visual experience. The interview participants believed there was great potential in using the LED system in ski filmmaking if the suggested improvements were made.

6.5 Feedback from Questionnaire

6.5.1 Quantitative Results

Figure 25 displays how 34 survey participants rated their interest in freeskiing on a scale from 1 to 5, with 5 being the most interested. The bar chart reveals that 64.7% of respondents rated their interest as 4 or 5, underscoring the effectiveness of the stated preference method used for participant selection. The chart also indicates the presence of participants with lower interest levels in freeskiing.

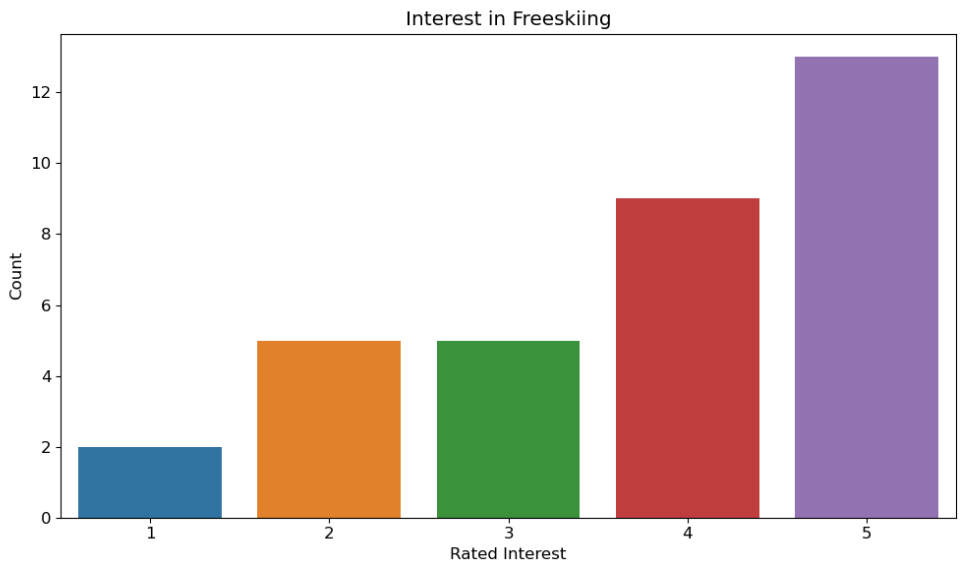


Figure 25: Level of interest in freeskiing among survey participants.

The numbers for the stated interest in freeskiing correlate with the numbers for how often the participants watch ski videos. About 44.1% responded that they watch longer ski films (>5 minutes long) every month or more often, and 64.7% stated that they watch shorter ski videos (<1 minute long) every month. Figure 26 displays the frequencies of watching short and longer ski videos among survey participants.

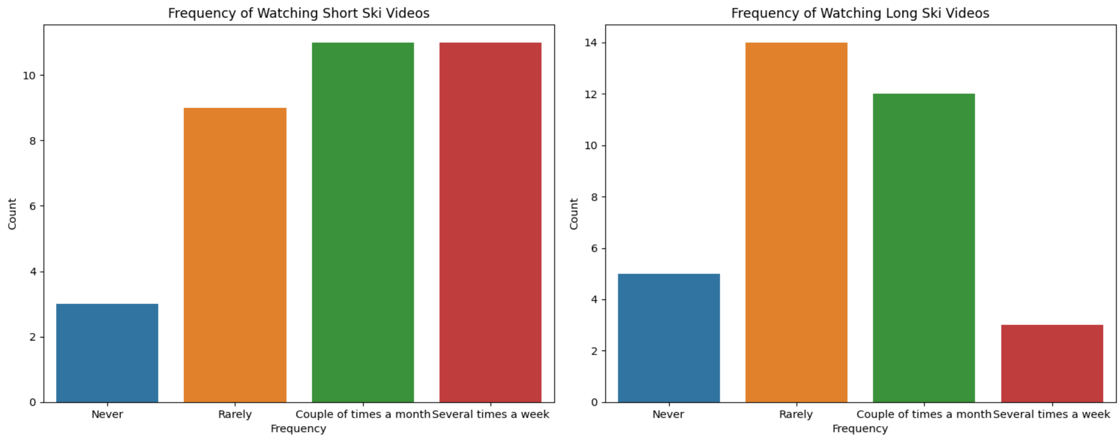


Figure 26: Frequency of watching short and long ski videos.

The participants were asked to rate several metrics about the video's perceived quality on a scale from 1 to 5, with 5 being the highest quality or most satisfactory result. The rated metrics included how much the video stood out from other videos they had seen (*Video Standout Rating*) and the effectiveness and brightness of the LEDs (*LEDs Brightness Effectiveness*). The respondents also rated their interest in watching a longer video with a similar LED system (*Interest in Longer Video*), the quality of the artificial snow particle effect (*Snow Particle Effect Quality*), and the visual effect created by the LEDs (*Visual Effect Quality Rating*). The results of the rated metrics are presented in Figure 27 and show that the ratings of the *LEDs Brightness Effectiveness* have the highest variance. The other four metrics all have similar ratings. Of the 34 respondents, 20 rated the *Video Standout Rating* a 4 or 5, and 4 participants rated it a 1 or 2. The *Interest in Longer Video* was rated a 4 or 5 by 18 respondents and 1 or 2 by 8 respondents.

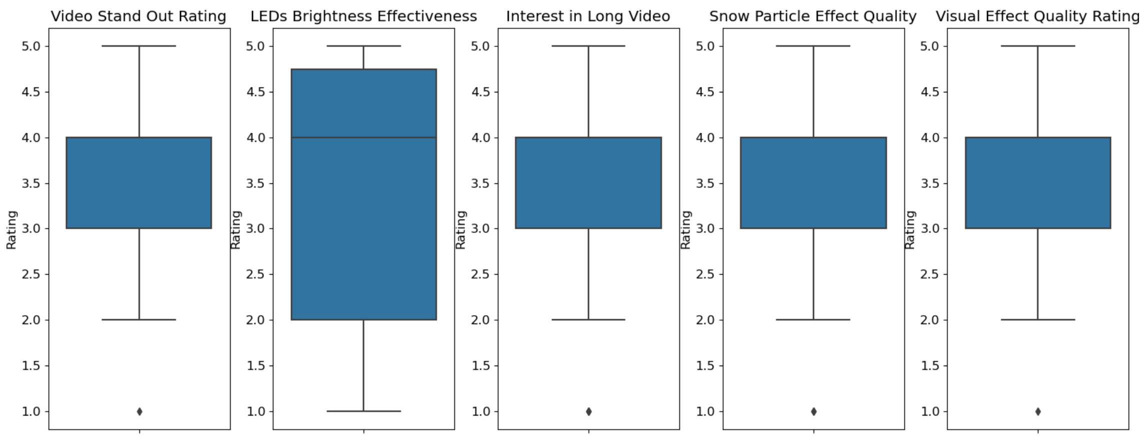


Figure 27: Box plots for various rating metrics.

A correlation matrix is created to see how factors such as interest in freeskiing correlate with other rating metrics. The correlation matrix is presented in Figure 28.

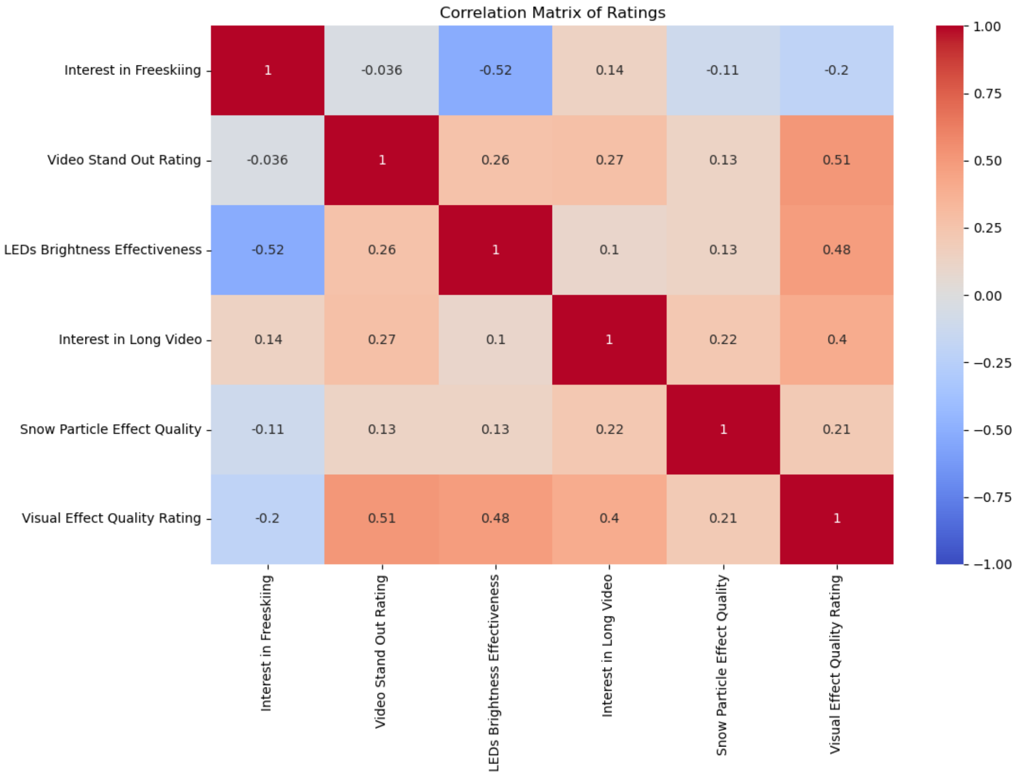


Figure 28: Correlation matrix of various rating metrics.

The correlation matrix shows a positive correlation between metrics such as the *Video Standout Rating*, *Visual Effect Quality Rating*, and the *Interest in Longer Video*. This indicates that respondents who rated one of these metrics highly tended to rate the others highly. In other words, respondents generally did not favor just one aspect of the video. If they appreciated one element, they would also likely appreciate the others. This suggests a holistic positive reception among viewers, where high ratings in one area were associated with high ratings across other areas.

The interest in freeskiing shows weak or insignificant correlations with metrics like *Video Standout Rating*, *Visual Effect Quality*, and *Interest in Longer Video*. This indicates that the general interest in freeskiing doesn't necessarily influence how respondents rate specific video qualities. However, the correlation matrix shows a negative correlation of -0.52 between interest in freeskiing and the *LEDs Brightness Effectiveness*.

Appendix A.2 includes the complete collection of quantitative results from the questionnaire.

6.5.2 Feedback From Free Text Questions

In the questionnaire, participants could add to their multiple-choice answers using free text and state what they liked about the video and what should be improved. Some viewers liked the creative use of LED lights and how they lit up the snow, making the scenes look better and keeping attention on the skier. Some liked the editing, such as the use of slow-motion, which made the LED lights and snow particle effect more noticeable and improved the video's look and feel.

Recommendations for improvements included increasing the brightness and coverage of the LEDs to illuminate the surroundings better. Adding LEDs to the skis and different parts of the body could help clarify the skier's movements and make the video more informative and visually appealing. The correlation between LED colors and the skier's movements could be made more apparent, and enhancements in night filming capabilities were also suggested to capture the terrain and the skier better. A need for improvements to the realism of the artificial snow effects in a clip with daylight was mentioned, as the current effect did not seem natural enough.

7 Discussion

7.1 Interpretation of Results

7.1.1 LED System Functionality

The functional verification of the LED system showed that requirements 1.1, 1.2, and 1.3 are met. The system responded to rotation with sufficient accuracy, and colors changed within $20ms$. This efficiency ensures that the system reacts quickly to movements, making color changes appear smooth and responsive.

The power supply's datasheet revealed that the stated temperature limitations of the power bank did not meet the specified numbers of requirement 2.1. However, during field testing, the power bank functioned well at temperatures below but close to the suggested minimum. It is worth noting that the power bank was placed close to the skier's body and was shielded from rain and wind. Because of this, the effective temperature on the power bank was likely to be higher than that of the skier's surroundings. If the LED system were to be used in temperatures well below freezing, one should consider replacing the power supply with one designed for colder temperatures to ensure that requirement 2.1 is met.

Based on the experience that the power bank had a relatively low decrease in battery percentage when used during the field testing for more than 4 hours in about 4-7°C, it is assumed that the battery life is more than 4 hours when used at 0°C, in line with requirement 2.2. The measurement of the current drawn from the LEDs supports this assumption. However, findings suggest that the LEDs are not fully utilized. According to [48], each LED draws about $50mA$ when set to full brightness and powered by $5V$, and when the supplied current is lowered, the brightness is reduced linearly. The results from the test showed that the consumption was only about $9.48mA$ per pixel, which is likely caused by limitations in the power supply module. The power bank's output limit of $3A$ means that it could supply a current per pixel given by:

$$Current/Pixel = \frac{3000mA - 125mA}{88} = 32.67mA$$

for a system with 88 pixels where the Arduino uses $125mA$ of the power budget. This implies that a power supply module with a higher maximum output current could increase the brightness of each LED. It is worth considering that the pixels use less power if only one of the red, green, or blue LEDs is on, which is typically the case for the color mapping used.

In the in-depth interview, it was suggested that the amount of light from the LED system was not high enough. This opinion was also reflected in some of the responses from the survey, both from the findings presented in Figure 27, where respondents disagreed when rating the metric about LED brightness and from free text answers. The survey results showed that participants with a high interest in freeskiing generally rated this metric lower. This could imply that those with a strong interest in freeskiing have different expectations for visual effects, although this is not supported by the ratings of other aspects of the video. From the recorded videos from field testing, it can be seen that the LEDs do not light up the surroundings to much extent, and for some clips, the strips of LEDs are the only thing that can be seen while the skier disappears in the dark. Adding lights to the skier's legs would significantly increase the overall brightness. This would require additional hardware, not only with the extra LED strips but also a different power supply module. For instance, if the number of LEDs is doubled to 176, a power supply module limited to $800mA$ would only give about $4.5mA$ per pixel. With a higher maximum output current, the $3A$ of the power bank could be fully utilized and give about $16.3mA$ per pixel. This is likely sufficient, as feedback from the interview stated that the brightness of each pixel was good enough in the tested system with $9.48mA$ per pixel. Small adjustments would also be needed to the LED algorithm and the wiring, though this work would introduce little additional complexity.

Feedback from the skier during field testing confirmed that having the LED system mounted on the body did not cause any problems or limitations to the skiing, and requirement 2.3 is considered met. Although the system did not bother the skier, questions were raised concerning its robustness in the in-depth interview with Frys Film. If the LED system is going to be used when skiing at high speeds or in rough terrain, the amount of force, twisting, and turning will be much higher than in the controlled circumstances of the field test. The concerns regarding the hardware were with the power supply module, but to meet the requirements set by high-speed off-piste skiing, a reevaluation of how to make the whole system more robust is needed.

7.1.2 Detection Models

The results presented in Table 7 and Table 8 show clear differences between nighttime and daytime performance. At night, all models struggle more than during the day. The pretrained models could not identify any objects at night, which suggests they do not work well in low light. The custom model did slightly better at night, with a recall of 0.09 and perfect precision, meaning it made few predictions, but those it did were all correct. However, many potential detections were missed.

During the day, the models performed much better. The pose estimation model had a recall of 0.46 and a high precision of 0.93, showing it can accurately detect and position objects in good lighting. The pretrained detection model, though less precise at 0.37, had the best recall during the day, indicating it responds well to better lighting. The custom model also improved in daylight, with nearly the same recall as the pose model and a precision of 0.78, confirming that lighting significantly affects how well these models work. In the daylight video, there are still many frames where the skier is visible, but the models cannot detect anything. It is likely that this is happening in frames where the skier is very small or partially covered by snow spray.

The evaluation of the detection models shows that despite training the custom model on a specialized dataset, it is outperformed when compared to the pretrained model for detection in daylight, as the recall of the pretrained model is 36.4% higher than that of the custom model. This highlights the capabilities of pretrained models that benefit from extensive training on large datasets and that the custom dataset may not have been sufficiently large or specialized to outperform the established model

The high amount of mispredictions with the pretrained model would not necessarily be a problem if utilized in this work, as most mispredictions could be filtered out by not considering classes other than *person*. Even though the number of correct predictions was lower for the custom and pose estimation models, these models had higher precision, and sufficient detection results can likely be obtained with these models in daylight. Given the performance of the pose estimation model, integrating it for both detection and pose estimation tasks could simplify the system's setup and reduce the complexity of the project, given that the recorded videos have sufficient lighting. An improvement to the current models or the skier's visibility is needed to perform detection in darker surroundings accurately.

7.1.3 Improvements Based on Feedback

Feedback from the in-depth interview and the skier's observations during field testing led to some immediate improvements to the project. One of these improvements was adjusting the LEDs' color mapping. During the field testing, it was noted how the skier's torso had little rotation, and the initial color mapping described in Section 3.1.2.2 resulted in little change in color as the skier skied down the slopes. The mapping from yaw rotation in degrees to color was updated to the one seen in Figure 29 for increased responsiveness.

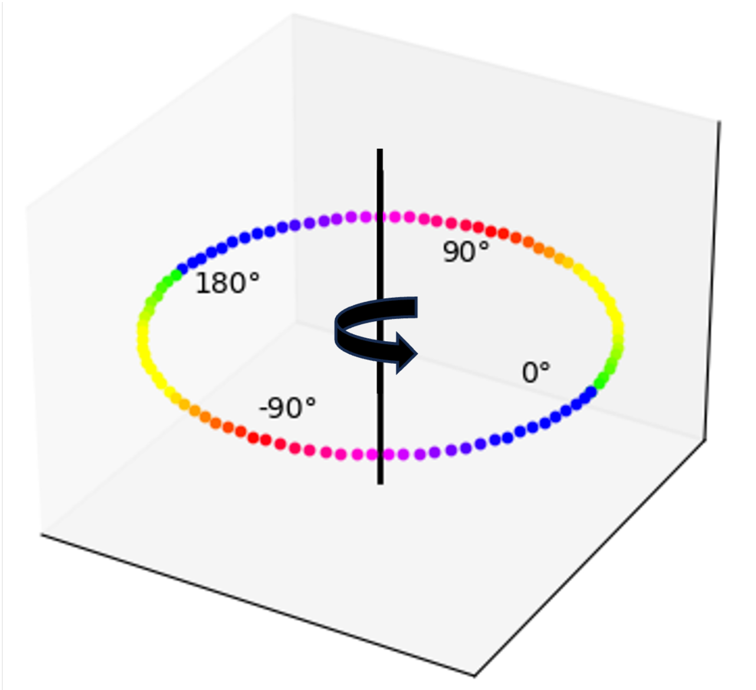


Figure 29: Updated mapping from yaw rotation in degrees to color.

During field testing, it was observed that the power supply module was fragile and that its USB input port needed additional protection. To solve this problem, a new protective case was designed, which includes support around the micro USB connected to the module. The updated case, which is presented in Figure 30, improves the current solution. A new case must be designed if the current power supply module is replaced with one that has a higher maximum output current.

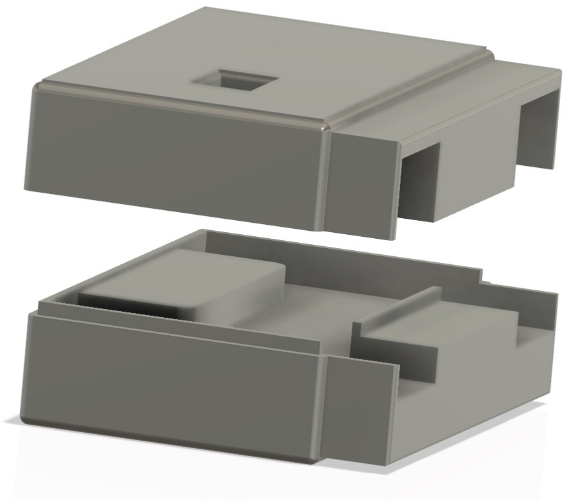


Figure 30: Updated protective case for power supply module.

7.1.4 Perceptions and Interest

For the survey questions that involved rating metrics from 1 to 5, a rating of 4 or 5 is considered high, indicating that the respondents have a positive impression of the perceived quality they are asked to rate. A rating of 1 or 2 is considered a low rating, indicating a negative perceived quality, while a rating of 3 is considered a neutral point of view. 58.8% of the survey participants gave the *Video Stand Out Rating* a high rating, and 11.8% gave the metric a low rating. This indicates that respondents generally found the video distinct compared to other ski videos they had seen. This suggests that the visual effects and the overall concept are perceived as innovative and fresh, which is an important finding as this work aims to find ways to create ski videos that are different from what the audience has seen before.

The *Interest in Longer Video* metric was given a high rating by 52.9% and a low rating by 23.5% of survey participants. This result suggests that the approach described in this work can capture interest over longer durations and that many viewers are interested in seeing more extended videos created using this system. However, the number of low ratings indicates that there is room for improvement in making the content more universally appealing and engaging to a broader audience. Some of these low ratings may be due to a general preference for shorter videos over longer ones. This preference is also reflected in Figure 26, which shows that survey respondents watch short ski videos more frequently than longer films.

The combination of ratings of the *Interest in Longer Video* and the *Video Stand Out Rating*, and that these ratings had little correlation with interest in freeskiing implies that a larger-scale ski video production has the potential to engage viewers within and outside the freeskiing community.

7.2 Future Work

7.2.1 Detection of Jumps

As suggested by the subjects of the in-depth interview, the current system could be improved by adding logic for making the LEDs react when the skier performs jumps or flips. The IMU data, specifically the linear acceleration in the vertical axis, can be used to detect jumps. When a skier takes off for a jump, there is a significant change in vertical acceleration due to the force exerted to leave the ground. Similarly, during flips, the IMU data will show distinct patterns of rotational acceleration. The system can detect when the skier is airborne or performing flips by setting thresholds for these accelerations. Combining this with a time threshold can help differentiate between regular skiing movements and jumps or flips. This data can trigger specific LED patterns, enhancing the visual effect and making the footage more dynamic and engaging.

Relevant insights are found in [49], which highlights using an inertial measurement unit (IMU) to analyze jump performance by measuring vertical acceleration and rotational velocities. It demonstrates high accuracy in measuring contraction time, flight time, and jump height. Similar methodologies can be used to detect and analyze complex movements such as flips and jumps in skiers. This involves leveraging the IMU's accelerometer and gyroscope data to detect rapid changes in motion and orientation and applying algorithms to differentiate between regular movement and jumps or flips. To improve the accuracy, using two IMUs instead of one should be considered, as research has found that two MPU6050s can achieve five times the accuracy of just one MPU6050 [50].

Another approach that could be used to detect force patterns that correlate with flips or jumps is to use force sensors in the skier's boots. In [21], it is found that force sensors, if placed correctly, can provide valuable data on skiing styles and movements. In addition to providing data for recognizing flips and jumps, the force sensor data could be used together with the IMU data to recognize the skier's turns with higher precision. This could provide a comprehensive understanding of the skier's movements, further improving the system's responsiveness and the visual feedback from the LEDs.

7.2.2 SD Card Module

An SD card module can be connected to the Arduino and IMU to save the yaw, pitch, and roll data for later. This can be useful when editing recorded videos in Unity, as the motion data and corresponding timestamps can be used to adjust Unity effects to match the skier's movements. Using the IMU data in Unity will likely give a more exact representation of the skier's turning compared to when a pose estimation model is used, as described in Section 3.2.4.

Although saving IMU data to a memory card can benefit the post-editing of videos, incorporating SD card writing into the script that manages the IMU and controls the LED strips presents several challenges due to the Arduino's limited processing power and memory. By using an I2C device library [34] to handle the data, the implementation of the AHRS is simplified. However, the library processes a lot of sensor data and uses significant system resources, which stretches the Arduino's capabilities. Adding SD card operations, which are slower and involve managing a file system, causes bottlenecks. The SD card writing can interrupt the smooth processing of sensor data and LED updates, and managing memory for both sensor data processing and SD card file operations can quickly use up the Arduino's available RAM.

In the current code for controlling the LED strips, the IMU sensor data is processed using interrupts to ensure timely and accurate data capture. This uses a significant portion of the Arduino's processing capacity. The I2C communication with the IMU and the calculations required for the AHRS put additional strain on the processor. The implementation of an SD card module with the LED algorithm was tested, and it was observed that the writing of IMU data caused the LED lights to flicker or turn off completely, suggesting that the system's performance is significantly reduced when attempting to handle both tasks simultaneously.

For future work, several solutions can be considered to address the challenges of integrating SD card writing into the LED and IMU system. One approach is to stagger the execution of tasks. Instead of performing all operations simultaneously, schedule them to minimize overlap. For instance, writing to the SD card could be performed at specific intervals or during periods when the system is less busy. Upgrading to a more powerful Arduino model, such as the Arduino Mega, which offers additional RAM and processing power compared to the Arduino Uno, could also help with the performance issues. This upgrade would provide more resources for concurrently handling sensor data and SD card operations, but it would also increase the system's physical size. Optimizing the existing code to minimize memory usage and ensure efficient handling of sensor readings and LED updates can help reduce delays.

7.2.3 Detection in Dark Surroundings and External Lighting

To improve the detection of skiers in low-light conditions, both model adjustments and improved lighting techniques can be explored. Improving the custom model might involve incorporating techniques such as integrating attention mechanisms that focus on more relevant features under dark conditions, similar to what is done in [51], or adapting existing models with specialized training on low-light images.

Another alternative for improving detection is to use external lighting systems to increase the skier's visibility. In addition to illuminating the scene and providing the necessary contrast for the detection models to function more effectively, these lighting solutions could enhance the visual effect created by the LEDs. A setup using static, colorful lights could provide a striking visual effect, similar to what is seen in [22], where external lighting with color creates a colorful palette, as illustrated in the behind-the-scenes photo in Figure 31.

Figure 31: External lighting used during the production of [22]. ©Oskar Enander. Used with permission.

To build on this, an approach with dynamic external lighting could be explored. For instance, the external lighting's brightness or color could dynamically change in response to the skier's movements, allowing the skier's dynamics to influence the LED strips and the surroundings. This could be implemented using ideas presented in [52], where a digital multiplex (DMX), a type of digital lighting control, is used to control LED fixtures. However, implementing dynamic external lighting would introduce complexities regarding the synchronization of data from the skier to the light controller, as ensuring real-time responsiveness without lag would require robust wireless communication protocols and efficient data processing algorithms.

7.2.4 Using Unity as Video Editing Software

One major challenge of adding effects to a video in a three-dimensional space is the size and depth customization required for realistic effects. The particle systems' parameters include values such as the particle size, speed, lifetime, and many more. To adjust the particle effects based on the skier's size, the particle system parameters are dynamically scaled according to the detected height of the skier as described for the emitting volume in Section 4.1.4.2. Additionally, the particle systems can be positioned closer to or further from the video canvas to achieve the desired visual impact, making the particles appear larger or smaller in the final output video. One of the particle systems' strengths is its numerous parameters, which allow for precise adjustments. However, tweaking these parameters involves significant manual adjustments and fine-tuning, which can be time-consuming and complex. For instance, when one parameter is scaled a certain amount, another parameter might require a different scaling to provide the desired result. The tuning of parameters is especially challenging when working with various videos, as finding settings that work well across different contexts is difficult.

A library of parameter templates and presets for different scenarios can be created in Unity to reduce the number of manual adjustments needed to adapt visual effects to a specific video. These presets can be selected based on the video type and the desired effects. For instance, there could be presets for different skiing conditions, such as powder snow and icy slopes, or different camera angles. Users can apply these presets with minimal adjustments, ensuring consistency and saving time.

Another challenge is that detection and tracking tasks are handled through external scripts rather than within Unity. This requires additional integration steps and potentially leads to workflow inefficiencies. With the introduction of *Sentis* [53], a neural network inference library for Unity that replaces the previously mentioned *Barracuda* library, the number of supported object detection models is extended and also introduces an improved API. At the time of the development of this work, *Sentis* was in a pre-release beta state, but a verified release was scheduled within a few months [53]. The release of the library is expected to simplify working with object detection directly in Unity, and it enables importing trained neural network models. By utilizing this library, detection models such as the pretrained YOLOv8 or an improved custom model trained on a larger dataset can be used within Unity.

7.3 Suggested Setup for Future Work

Figure 32 illustrates the possible layout for a future iteration of this work and summarizes the suggested improvements presented in this section. It uses a structure similar to the diagram presented in Figure 3. The pink blocks include the improvements to the LED system, and the blue blocks show the components of the editing process in Unity. A key difference that can be seen when comparing Figure 32 to Figure 3 is how all data processing performed in the editing part of the workflow is done in Unity. The suggested improvements still require data to be imported to Unity, as the recorded data on the memory card has to be added to the Unity project, but the overall workflow is more streamlined.

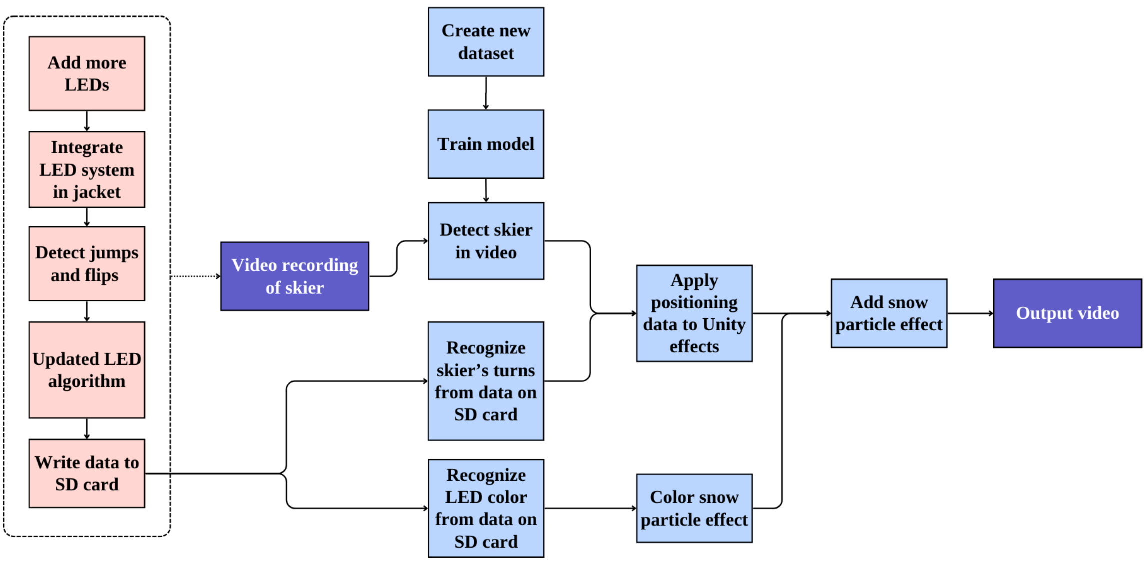


Figure 32: Block diagram illustrating a layout for a project with suggested improvements.

A potential larger-scale production using the suggested setup, with more careful planning of skiing routes, tricks, and clip choices, could greatly improve the final video. By selecting scenes with variations in skiing styles and using dynamic shots, the video would become more visually appealing and interesting. Adding background music that matches the skiing and lighting effects would make the video more engaging, and the music could be combined with brightness adjustments to adjust the intensity of the video. Combining technical and artistic planning would create a more professional-looking production that better meets the high standards of state-of-the-art films.

8 Conclusion

This work aimed to explore a new approach to creating interesting and visually appealing ski videos by integrating LED technology and digital effects. A system with several components was designed, including a dynamic LED setup mounted to a skier. This was controlled by an Arduino, which adjusted light patterns based on IMU data, providing a dynamic visual element. A YOLOv8 detection model trained on a custom dataset tracked the skier's movements in recorded videos. The detection data was utilized during post-processing, where Unity's particle systems were used to create artificial snow spray effects. A field test was used to evaluate the LED system in a natural environment, and recordings from this test were used in a survey to get feedback from people who had no association with the project. In addition, an in-depth interview with experienced skiers from a film production company and verification tests were used for evaluation. The work has laid a foundation for developing compelling ski videos by combining dynamic lighting and Unity for video editing. The initial results demonstrated significant potential, but several areas required further improvement and refinement to realize this goal.

The lack of sufficient lighting was a significant challenge. This was not only because it complicated data processing and skier detection but also because it reduced visual quality. The in-depth interview specified that the number of LEDs should be increased, as it would improve the effect if the terrain surrounding the skier were illuminated and given the same color as the LEDs. This feedback was also present in some of the responses to the survey. To address the challenges associated with the shortage of light, future developments of this work should include more LEDs and external lighting to enhance visibility and improve detection accuracy, especially in dark environments. The current power supply module should be replaced because the existing module's maximum output current is insufficient to provide the required brightness for a larger number of LEDs, and a more robust module is needed to ensure the system's robustness.

The detection model was trained on a custom dataset of images from professional alpine and freestyle skiing. When evaluated on a video recorded in daylight, the recall of the custom model was 0.44, while the recall for a pretrained YOLOv8 detection model trained on the COCO dataset was 0.60. However, the custom model showed promising signs as it could detect a skier in dark surroundings when pretrained models did not. Still, the accuracy of all models was low for all models for a video recorded at night, and adjustments are needed to improve detection in darkness. In addition to adding external lighting and more LEDs, the custom model could be specialized in detecting objects in low-light conditions by re-training it on a dataset with more images taken in such conditions.

A logical next step for further development is the detection of jumps and flips. This feature would enhance the videos' visual appeal by adding more dynamic elements, which can broaden the range of captured actions and enhance the visual storytelling of the skier's performance. This could be achieved by refining the current LED system algorithm and using more of the data already collected by the IMU or by adding force sensors to the ski boots. In addition, the robustness of the LED system can be improved by integrating the system into a jacket for easier mounting. Future work could also include implementing an SD card to store the collected IMU data and use this in post-processing. To do this, a restructuring of the current LED system algorithm or updated hardware is needed to maintain the smooth processing of sensor data when slow writing operations are added.

The work showed that Unity can be used to add effects to videos. This worked particularly well for recordings made with a static camera. However, dynamic shots required manual editing, which was more time-consuming. It was also harder to create realistic particle movements for dynamic shots as the size and depth adjustments of the effects placed in Unity's 3D environment proved to be difficult. Improving the system to handle dynamic footage more effectively and automatically would greatly expand the versatility of the editing. Creating a complete video editing tool within Unity that integrates detection and editing processes would improve the workflow and usability. The constant improvements and updates of Unity and available libraries are expected to simplify this process.

The feedback from the in-depth interview with film industry professionals and the survey results underscore the LED system's significant potential and innovativeness for ski video production. The interview highlighted the dynamic nature of the LED lighting changes as a feature that sets the system apart from traditional ski video productions. Also, the visual effect was significantly enhanced when the system was used in dark environments.

Survey results indicated that viewers found the videos distinct and engaging. The feedback suggested that the system presented in this work has the potential to captivate audiences and create memorable ski videos. With the recommended improvements, the system could become a valuable tool in ski filmmaking, offering new creative possibilities and setting a new standard for visual effects in the industry.

In summary, this work has demonstrated the potential of combining LED technology with digital effects to enhance ski videos. The integration of augmented reality tools and sensor data can pave the way for a new approach to ski film production. By utilizing these technologies, filmmakers can create more engaging and dynamic content. While promising, the system requires further development to overcome the identified practical challenges. Future work should focus on improving lighting, utilizing more of the collected sensor data, and simplifying the setup process to make the system more practical.

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Appendices

A Survey

A.1 Questionnaire

Ski Video Feedback

By participating in this study you approve to the following conditions: All the data that you provide during this experiment will be pseudonymized. During the experiment, you have the chance to leave the study without the need to provide any reason. All recorded data will be saved and will be used pseudonymized (e.g. identification data will stored separately from recorded data and only be accessible to a small circle of authorized personnel) for research analysis. All data from the questionnaire will be handled confidentially. All information will be used for research purposes only. Personal data will not be given to any third party.

Introduction

Thank you very much for your participation in this experiment. This study will last no longer than 10 minutes and includes watching a video and giving feedback on its content. As part of a project where the goal is to explore innovative approaches to making and editing ski films, an LED system that responds to a skier's movements is created. To test the LED system, video clips of a skier using the system at night time are recorded. In addition to the visual enhancements created by the LEDs, effects are added using the Unity Development Platform.

Respondent Background

1. How often do you watch ski videos on social media, YouTube or from other sources?

Markér bare én oval per rad

	Never	Rarely	Couple of times a month	Several times a week
Short videos (<1 minute)	◯	◯	◯	◯
Longer videos or films	◯	◯	◯	◯

2. Rate your level of interest in freeskiing

Markér bare én oval.

	1	2	3	4	5	
No in	◯	◯	◯	◯	◯	Very interested

Video

The video below shows clips from a test session were an LED system with lights that change based on movements was used. An additional snow spray effect is added to some of the clips.

LED Test Video

 http://youtube.com/watch?v=F8SjDWHWR2g

3. Rate how much this video stands out from other videos you have seen?

Markér bare én oval.

	1	2	3	4	5	
Not a	◯	◯	◯	◯	◯	Very unique

4. Rate your interest in watching a longer ski video (>5 minutes) where an LED system similar to the one in this test video was used?

Markér bare én oval.

	1	2	3	4	5	
No in						Very interested

5. Are the number of LEDs and their brightness high enough to create a significant visual effect?

Markér bare én oval.

	1	2	3	4	5	
Not a						The current levels are high enough

6. Rate the quality of the artificial snow particle effect that is added to some of the clips

Markér bare én oval.

	1	2	3	4	5	
Very						Excellent

7. Rate the quality of the visual effect created by the LED system

Markér bare én oval.

	1	2	3	4	5	
Very						Excellent

8. If not covered by your previous answers, what did you like about the video?

9. If not covered by your previous answers, what adjustments should be made to improve the system and effects in the video?

Final Section

Thank you for your participation! Continue to the next page to send in your answers

A.2 Responses

How often do you watch s	How often do you watch s	Rate your level of interest	Rate how much this videc	Rate your interest in watc	Are the number of LEDs a	Rate the quality of the arti	Rate the quality of the visi
Couple of times a month	Rarely	4	5	4	2	4	4
Several times a week	Couple of times a month	5	2	2	1	4	2
Several times a week	Rarely	4	3	2	1	4	1
Couple of times a month	Couple of times a month	3	4	5	4	5	3
Several times a week	Couple of times a month	5	3	5	2	3	3
Several times a week	Several times a week	4	3	1	3	2	2
Rarely	Couple of times a month	5	5	3	5	4	4
Couple of times a month	Rarely	4	4	4	5	3	3
Several times a week	Couple of times a month	4	4	5	3	5	3
Couple of times a month	Couple of times a month	5	4	4	4	5	5
Several times a week	Several times a week	4	5	2	4	4	3
Couple of times a month	Couple of times a month	5	4	4	4	3	4
Several times a week	Couple of times a month	5	4	4	2	3	3
Couple of times a month	Rarely	4	3	3	3	3	3
Rarely	Rarely	5	3	4	5	2	4
Never	Never	2	5	3	5	4	5
Rarely	Rarely	1	4	5	5	4	4
Several times a week	Several times a week	5	5	3	2	1	3
Never	Never	1	4	4	5	3	4
Rarely	Never	2	4	3	5	4	4
Couple of times a month	Rarely	5	2	4	1	4	4
Rarely	Rarely	2	3	3	4	3	3
Several times a week	Couple of times a month	5	4	5	5	4	4
Couple of times a month	Rarely	3	5	4	4	3	5
Couple of times a month	Couple of times a month	5	4	4	3	3	4
Rarely	Rarely	3	5	4	4	4	4
Rarely	Rarely	2	3	2	4	3	4
Several times a week	Rarely	4	4	4	2	1	3
Rarely	Never	3	2	1	5	3	2
Never	Never	2	1	2	4	3	3
Rarely	Rarely	3	5	1		3	4
Couple of times a month	Rarely	4	3	4	4	2	3
Couple of times a month	Couple of times a month	5	3	3	1	3	3
Several times a week	Couple of times a month	5	3	3	2	3	2

NTNU

Norwegian University of
Science and Technology