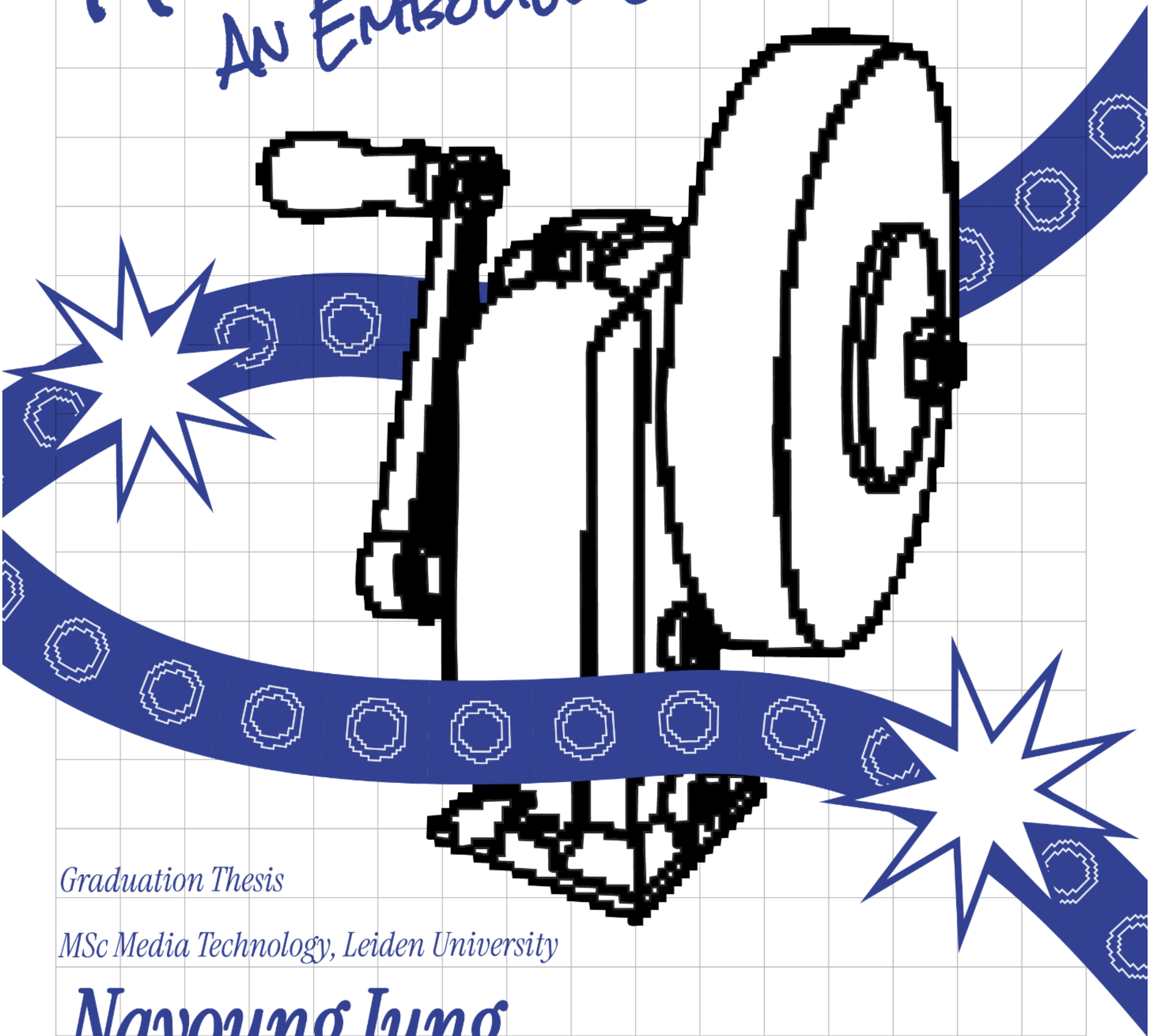
More-Than-Switch: An Embodied Light Control



Graduation Thesis

MSc Media Technology, Leiden University

Nayoung Jung

Supervised by ***Edwin van der Heide*** *(primary) and* ***Fons Verbeek*** *(secondary)*

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Abstract

Cranking has been used in various contexts as a means of input from generating power to a controller for a game device, but its usage to control the light has not been actively implemented. To discover its potential for interaction design, this study explores cranking both as a direct form of control and as an input of an interactive dialogue between the light and us. These are achieved through iterative prototyping. Various setups were explored using Arduino modules, and discrete and continuous sensors mounted to the crank input- either as a crank handle or a grinding wheel. The cranking direction or speed controls the light's brightness, colour and movement. The implementations are evaluated by the researchers based on five criteria: controllability, repeatability, understandability, intuitiveness and engagement. From the 34 experiments, the results showcase that controlling the cranking direction with the small crank handle that does not have inertia can be more useful in obtaining an intended value, while it can be difficult to control when one full-handle rotation can reach the entire value. It also shows that cranking speed with the small crank handle is difficult to control due to the absence of inertia and its small size. The grinding wheel has difficulty stopping cranking or changing the cranking direction promptly due to its high inertia. Yet it is useful in speed-based control setups to maintain cranking at a constant speed. Despite some limitations of the lab setup, the most promising interactive dialogue is shown where the grinding wheel's speed controls the light's movement. With the wheel's high inertia that facilitates accelerating or decelerating the light's movement, one can choose whether to support or go against it. The study points out that the implemented interactive dialogue engages our body to be part of the experience. The physical sense, like inertia that is felt through our body, enriched the experience and encouraged active immersion. From there, the study concludes with the core message- cranking can be more than a switch.

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1 Introduction

Think about how you turned on the light when you entered a room to read this. Did you press the switch? Did you clap to activate your light? Researchers have proposed numerous ways to interact with lights through tangible-embodied interaction to enrich how we engage with lights (Offermans, 2016; Li et al., 2020). Yet, under most circumstances, the interactions with light are very standardised and utilitarian. The switch is turned ‘on’ to turn ‘on’ the light, or a button is pressed multiple times to adjust the brightness. Starting from here, the study looks into a new direction for embodied light control that goes beyond the on-off mechanisms, developing a novel interaction. This chapter will begin with discussing the concept of embodied interaction and the research gap we chose to explore, analysing crank-based interactions from historical contexts to HCI context, and eliciting what we can apply from the analysis into this study.

1.1. Embodied Interaction

Embodied interaction is built upon the duality of mind and body, highlighting the interaction between them, and it can scaffold the way we can be in the world (Dourish, 2001; Van Dijk, 2018). This concept is often discussed in the domain of human-computer interaction (HCI). Hornecker (2011) suggested that computer interactions must align with human innate abilities and the connection between our bodies and the physical world. Leveraging our body’s innate intelligence enables the creation of a tight coupling between perception and action (Hornecker & Buur, 2006) and further achieves a more intuitive, seamless user experience. In the field of embodied interaction, hand-based interactions can offer rich experiences through the wide range of gestures and the intricate control of hand movements (Buur et al, 2004). In the context of embodied interaction with light, researchers involved diverse hand-based gestural behaviours in the interaction, like holding, touching, pushing, in-air gestures, pressing, and combinations of multiple models (Li et al., 2020). Among these hand-based actions, rotation-based gestures are commonly found in daily life, such as dimming the table lamp light by turning a knob or rotating the colour wheel on the smartphone screen to change the light colour. Offermans (2016) introduced a HueCube interface, a wooden cube for the Philips Hue lighting system operated by a rotation-based interaction. As a cube interface, it relies on the position of the cube, and each side has a visual symbol where users can grasp the function without operating it; this aligns with Djajadiningrat et al (2007), mentioning modern design often prioritises less physical and less expressive configuration in interactions. Given ideas from this, we chose to focus on crank-based interaction among the rotation-based interactions. Cranking has been used for various examples in different domains throughout history and in the HCI context. Its interaction is simple and straightforward and its diverse intrinsic characteristics have the potential to shape interactive experiences (Lundström & Fernaeus, 2022). Cranking may not be ideal in utilitarian contexts, though it can be very logical and engaging in an HCI context. Considering its novelty in the context of embodied interaction for lights, this study specifically chose crank-based embodied light control as a topic.

1.2. Crank Analysis

To expand our understanding of crank-based interactions, we begin by examining various crank examples and look at which aspects of crank-based interaction can be applied to our study. The examples cover more general contexts and a typical HCI context.

1.2.1. Crank in general

Cranking has been served for various purposes, such as an input mechanism for musical instruments to a means of generating power. In the following section, we will discuss a range of examples: a music box, a hurdy-gurdy, an old telephone and a dynamo-based camping light. We do this because we have different approaches towards interaction that can spark ideas in the context of our study (Figure 1).

<Figure 1. Crank examples in various contexts. From left to right: a music box, a hurdy-gurdy, an old telephone, and a dynamo-based camping light. *See Image Credits for details.*>

1) A music box: This mechanical musical instrument produces sound through a set of metal-plated pins plucked by a rotating cylinder. When cranking the handle, the friction of the cylinder generates immediate auditory feedback, which is a looping sound sequence. The crank handle's angular position corresponds to a relative position in the cylinder, which aligns with different parts of the musical score. This interaction is directly controlled by the user's input because the sound stops when cranking stops while both the crank handle and the cylinder maintain their positions, and it can be interpreted as humans being fully in charge of the cylinder's movement.

2) Hurdy-gurdy: To play this historical musical instrument, one hand presses keys to produce specific musical notes, while the other turns a handle attached to a wheel that rotates against the strings. When turning the bi-directional handle[1], users feel the tension and friction against the strings, guiding them to adjust their control input accordingly. When releasing the handle, its angular position suggests where the input was left off. The mechanism can be modified depending on the user's intention to enrich the sound effects, such as loosening the screw so that the handle can stay in motion due to inertia when releasing the handle. The interaction starts with the users directly controlling the handle to produce the sound. However, when the handle stays in motion, they adapt how they crank by waiting for the handle to stop or turning it harder to support its rotational movement. This aspect can be interpreted that there is a mutual influence and that the artefact can initiate the interaction.

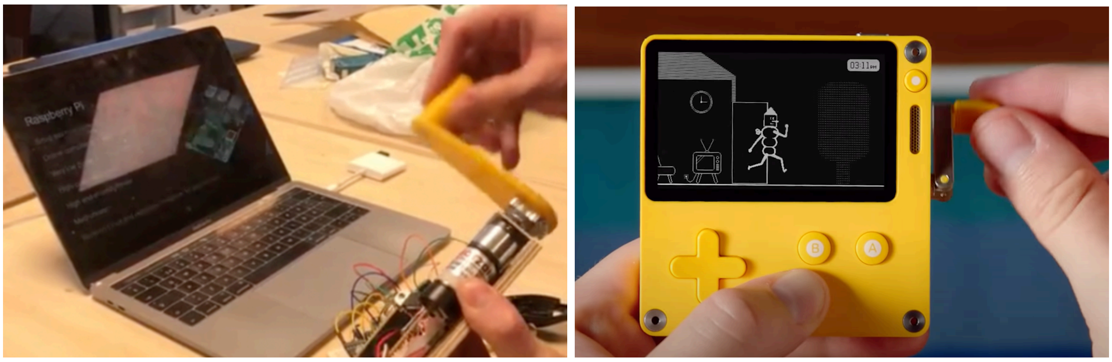
3) An old telephone: When the user turns the handle, a dynamo in its structure turns the magnet to generate an electric current in the coil. The faster the handle turns, the quicker the energy is generated and the faster the users can make a call. When the energy is sufficiently generated, the device produces a dial tone, prompting them to stop cranking. Even if the cranking's angular position does not correspond to the value, the system's feedback can inform the users to what extent their input is being registered.

4) Dynamo-based camping light: While cranking, the internal dynamo converts the physical input into electrical energy, which generates power for the built-in light bulbs. The amount of rotation influences the intensity of the brightness; more rotation produces more power, resulting in a brighter light. When the handle is released, the energy is accumulated and is released gradually. This can be interpreted as the artefact needs the user's direct but temporary input as a power source for the long-lasting effect.

1.2.2. Crank in HCI

Several recent studies in HCI incorporated cranking as the major form of interaction and proved its potential for engagement (Jacobs et al., 2016; Lundström & Fernaeus, 2022) as shown in Figure 2.

[1] A bi-directional rotation is possible for the contemporary ones, while the traditional ones only allowed for a one-directional movement (Nowotnik, 2012).



<Figure 2. *Slideshow* (Lundström & Fernaeus, 2022) and Playdate. *Retrieved from* https://play.date.>

1) Slideshow (Lundström & Fernaeus, 2022): The system tracks the angular changes of the crank handle and determines whether to go to the previous or next slide. This lightweight crank handle remains in its position when cranking stops. This example mentions that the interaction can be more responsive and intuitive by simulating a behaviour that the system immediately updates as soon as the input changes. This can further illustrate how the system measures the input, which can be modified depending on the intention of the experience.

2) Playdate[2]: With the cranking as an input, this game console simulates various actions, like steering a boat, generating power, or winding a camera reel. It shows that HCI can simulate dynamic behaviours from the cranking input.

1.3. Reflection

In 1.2 Crank Analysis, we examined how cranking has been used as a form of control in diverse contexts. In such interactions where cranking serves as an input mechanism, the user often is the most responsible one in the experience; the interaction stops when the user stops cranking. Yet, from the hurdy-gurdy, we saw that the performer changes their input movement depending on the output. This suggests that the object or the system can also initiate interactions, reversing the role between the input and the output. Reflecting on this, we observed that cranking can be used not only as an input for direct control but also as an input for communicative experience between the system and the user. Despite this potential, cranking as an input for embodied light control is yet underexplored (Li et al, 2020). As 1.2.2. Crank in HCI shows, the application of HCI enables us to simulate various forms of cranking-based interactions, and thereby it can be logical and interesting to use it to realise a crank-based light control. With these in consideration, the next chapter 2. Research Design will explain our approach in detail to explore the crank-based interactions.

[2] Panic Inc. (n.d.). Playdate. Retrieved March 13, 2025, from https://play.date

2 Research Design

Considering the novelty of the topic, we will begin the study by exploring the foundational logic in converting the cranking input into the light display as a direct form of control and later expand our approaches to use cranking as part of an interactive experience. In this chapter, we will explain our approaches in detail, including the research question, the structure of the experiments, the terms and concepts that the study will use, and the evaluation criteria for the experiences.

2.1. Research Question

To guide us to reimagine and expand the potential of crank-based interaction by exploring different crank-based interfaces, we formulated the following research question.

"What forms of crank-based interaction can we imagine in the context of embodied light control?"

2.2. Approaches

To answer the research question, our study covers two directions. Firstly, we focus on cranking as the direct form of control. When designing an embodied control, the physical input should receive direct and immediate feedback from the system (Schubert, 2021). Given this, we begin by examining how to capture the cranking input and translate it into a simulated behaviour that feels aligned with our expectations from cranking. The direct form of control refers to a way to immediately obtain an intended value when input is applied. However, cranking is a continuous action that not all the variables can be measured as a discrete, temporary value; for instance, cranking speed is measured over time, suggesting there can be a limit to creating a crank-based direct form of control. Yet, as the hurdy-gurdy showed, the user adapts the cranking behaviour depending on the system's reaction, and this can be further interpreted as an audience-artwork interaction where the system and the user both influence each other as a form of an interactive dialogue (Schraffenberger & van der Heide, 2012). Thus, it is relevant to expand our approach towards the crank-based interactive dialogue to discover the aspects that the direct form of control does not touch upon, such as implementing dynamics between the light and us and examining how the input influences such interactive experiences. This process will be referred to as *creating an interactive dialogue* from now on. With these in consideration, Chapter 3. Discrete Sensor: Experiments and Chapter 4. Continuous Sensor: Experiments will implement numerous setups to control the light by using different sensors, and crank handles, and modifying the light display. Each chapter will explain how we created an experience and evaluate the experience. Chapter 5. Conclusion will summarise findings from the experiments and provide suggestions for further studies. The following shows the detailed approaches of our study.

1) Research-Through-Design: This study follows the research-through-design format suggested by Baalman (2022). It aims to examine the control setup and explore various implementations. The outcomes of each chapter are used to refine the subsequent research directions. The follow-up experiments complement the aspects that the previous experiments did not achieve. The whole process was managed by researchers alone, without involving participants, for practical reasons. To validate the experiments, researchers' expertise in HCI and iterative experiments were involved.

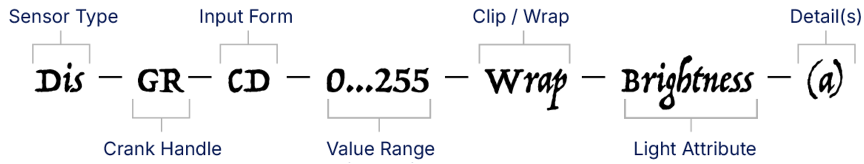
2) Experiment structure: There are two main chapters in this research- Chapter 3. Discrete Sensor: Experiments and Chapter 4. Continuous Sensor: Experiments. Each aims to compare how the discrete sensor and the continuous sensor capture the cranking input and explore how we apply their characteristics to the interaction between the light and the user. It follows an identical structure- (1) form (2) translation, where it shows how the mechanical input from cranking is converted to an output for the light, (3) evaluation and (4) discussion and conclusion. The interaction in the experiments shared the identical logic developed by the researchers (Figure 3).

< Figure 3. Interaction flow diagram >

3) Basic terms and concepts: Bakker et al (2012) and Lundström & Fernaeus (2022) categorised crank-based interfaces based on their setups and their observable characteristics, such as *cranking direction* (clockwise/anti-clockwise), *plane position* (horizontal/vertical), *speed* (fast/slow), and *hand grip* (one-handed/double-handed). Although it gives a foundational overview of the crank elements, those studies take different directions than our embodied light control context. Also, experiences surrounding the input configurations, like the crank interfaces and the value range for the output can be more can be specified through comparable experiments. Considering the scope of the study and the study context, we chose to focus on two input forms: ***cranking direction*** (clockwise/anti-clockwise) and ***speed*** (fast/slow) of cranking. Details will be discussed at the beginning of each chapter, such as how the handle's angular position is implemented (absolute or relative) and how we treat the value (clipped or wrapped). *Clip* refers to limiting the values in a predefined range, while *wrap* refers to looping the value around the range. The experiments use a discrete sensor or a continuous sensor mounted to a crank handle (**HANDLE**) or a grinding wheel (**GRINDER**). It does not discuss certain mechanisms of crank interfaces, such as table-top cranks, winding drum cranks, spiral cranks and others, because examining these specific mechanisms is beyond the scope of our study.

The cranking input in this study controls (1) brightness, (2) colours and (3) movement of the light, given the ideas from the previous researchers in the domain of this study (Li et al., 2020). Brightness and colours can often be found in daily lighting control interfaces. Those are often controlled by the rotation-based input, particularly the colour control, which is based on the hue cycle in the HSB (Hue, Saturation, Brightness) system. Also, as the dynamo-based camping light showed, cranking can be simulated to control the intensity of the brightness. The movement control can be implemented in diverse ways considering the use of an LED strip that can create various animations, and we are interested in how cranking can control this movement. Attributes like temperature, strobe and shape (soft/hard) were intentionally excluded to keep the research more focused since these would bring additional complexity during the process. Each setup controls each attribute separately unless it is needed to implement a specific visual effect in the experience. Given many experiments with different conditions, the study uses annotations to clarify their traits based on the following logic.

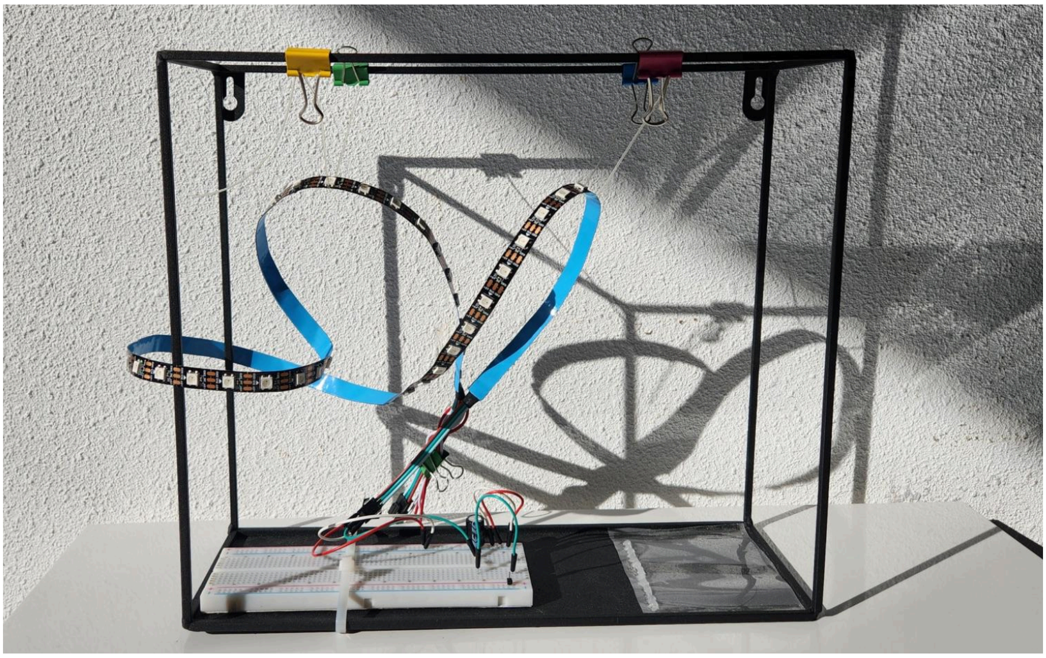
Example:



- **Dis-GRINDER:** 'sensor type: discrete sensor (Dis) or continuous sensor (Con)' or and 'crank type: handle (HANDLE) or grinder (GRINDER)'
- **CD**: Input forms, such as Crank direction (CD) or Speed (SP)
- **0…255**: Value range
- **Wrap**: Clip/wrap
- **Brightness**: Light attributes, such as brightness, colour, or movement
- **(a):** Detailed condition, referred to as (a), (b), or (c)

This study will often use the term ‘translation’ instead of ‘mapping out’, because we are more interested in converting input action into experiential system responses, rather than merely establishing clear one-to-one connections between input and output.

4) The setup (microcontroller and sensors): The experiments used Arduino UNO, a microcontroller that converts physical inputs into digital outputs for various ways of light display. To capture the cranking movement, we use two sensors throughout the process- an endless bi-directional rotary encoder and a 360-degree continuous potentiometer. These sensors were chosen based on Baalman's (2022) criteria, such as their intended use, accuracy, and practical aspects. We execute comparable experiments considering the sensors’ different characteristics to measure the value. Arduino and the sensors will control the light source- LED strip WS2812B with 60 LED lights, which was selected for its capability for a diverse light display and its ease of integration with the Arduino. The LEDs are based on RGB (Red, Green, and Blue), and each LED is capable of 256 levels of brightness per colour channel. Our experiments used the HSB system for an efficient and effective calculation process. Except when using the *motion* of the light, all the LED lights are programmed to be controlled simultaneously. In this study, *brightness* refers to how bright each LED pixel can emit within the scale 0 (no brightness) to 255 (full brightness). *Colours* refer to the levels of both hue and saturation. The hue values range from 0 (red, followed by yellow and green) to 360 (red, after passing through blue and purple), which is typically shown in a cyclic pattern. As the cyclic representation naturally aligns with the cranking motion, it is relevant to involve it in this study context to create an intuitive, continuous interaction. *Motion* refers to the movement of the light source. Since Arduino can control each light pixel, we implement this by lighting up one LED burning at a time on a looped LED structure, which contains 60 pixels (Figure 4).



< Figure 4. Lighting System setup >

5) Evaluation: To evaluate the tangible interaction, Hornecker & Buur (2006) suggested *tangible manipulation*, *spatial interaction*, *embodied facilitation*, and *expressive representation*. Marshall (2009) mentioned *ease of use, controllability*, *engagement*, *entertainment*, and *potential for further performance*. Other researchers mentioned *repeatability*, indicating the repeatable outcome in most instances from the carefully defined (Haansman, 2003) and *reproducibility*, indicating validation and the generalisability of the concepts (Adams et al., 2008; Lallemand, 2015). Drawing ideas from these, we devised criteria tailored to the context of this research, aiming to explore an intuitive crank-based control:

- ***Controllability*** (How much the user's input is in control of the interaction)
- ***Repeatability*** (Whether the interaction can easily be replicated under the same conditions)
- ***Understandability*** (How clear it is to understand the connection between the input and the output)
- ***Intuitiveness*** (How easily users can engage with the interaction without prior knowledge or instructions)
- ***Engagement*** (How entertaining and captivating the interaction is)

Based on these considerations, the following chapters will explore a series of crank-based interactions where various crank interfaces can intuitively control the light and an engaging experience as if both we and the light respond to each other's input and outputs. The first experiment begins with using a discrete sensor to simulate the crank-based light control.

3. Discrete Sensor: Experiments

We use an endless bi-directional rotary encoder (KY-40) to obtain an intended value to control the light attribute by cranking. In the next two chapters, the experiments are managed in two folds: (1) where the crank handle is directly connected to the sensor and (2) where the sensor is mounted to the grinding wheel. The sensor sends 30 pulses per rotation, which indicates the light value would be updated on a big scale if one full handle turn corresponds to the entire value range with the chosen sensor. Considering this, we simulate a behaviour where multiple turns of the crank handle are required to reach the maximum value so that cranking can update the value at a small scale. In Chapter 3.1. Crank Handle (**Dis-HANDLE**), the values for all the light attributes are clipped at their respective minimum and maximum to limit the values within the light's range. Chapter 3.2. Grinding Wheel (**Dis-GRINDER**) executes comparable experiments and complements the experiences that **Dis-HANDLE** did not cover. With the requirement of the multiple handle turns, we simulate the system that updates the value immediately when the cranking direction shifts, given ideas from *Slideshow*, showing this implementation can make the control intuitive and efficient without the need to crank back when the exact number of rotations remains uncertain while turning the handle. This further leads us to implement a relative form of control where the handle's angular position does not correspond to the value. The following shows how each input form is being used in the experiments.

- **Cranking direction (clockwise/anti-clockwise)**: The sensor can measure the +1 or -1 by default. Each refers to increment by one and decrement by one. Multiple rotations correspond to the full range. As the sensor gives pulses per rotation, the input value from the sensor is shown as an 'int' variable in the code. This will be referred to as **CD** on the following pages.

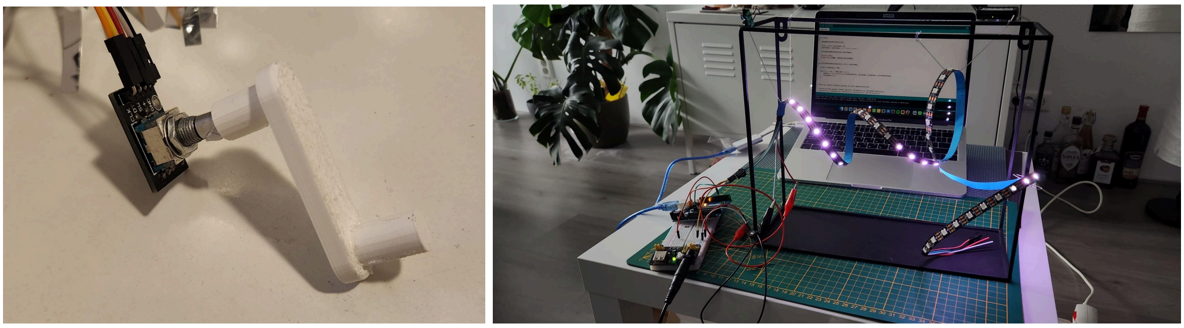
- **Speed (fast/slow):** We calculated speed and direction by measuring the elapsed time (Δt) between the current and the previous sensor positions ($\Delta\theta$) in the following formula 'speed = $\Delta\theta$ / Δt'. This is recorded in milliseconds for precision. The speed is normalised in the range of 0 to 100 and mapped to the light attributes' value. 0 refers to no update in the handle's positions and 100 corresponds to the maximum rotational speed that we can achieve when turning the handle. For higher precision in measuring time, we use 'float' variables, which are converted into 'int' variables that align with the required value for the light system. In this formula, 'angular velocity' is the correct term, however, we use 'speed' to keep the description compact. This will be referred to as **SP** on the following pages.

3.1. Crank Handle (Dis-HANDLE)

Considering this is the first step in this study, we chose to simulate the familiar interactions in the example of a *music box* and *Slideshow* where the user directly controls the system by turning the handle multiple times. Through this approach, we aim to formulate an initial understanding of the crank-based interaction. The title of the chapter will be referred to as **Dis-HANDLE** in the following pages.

1) The form

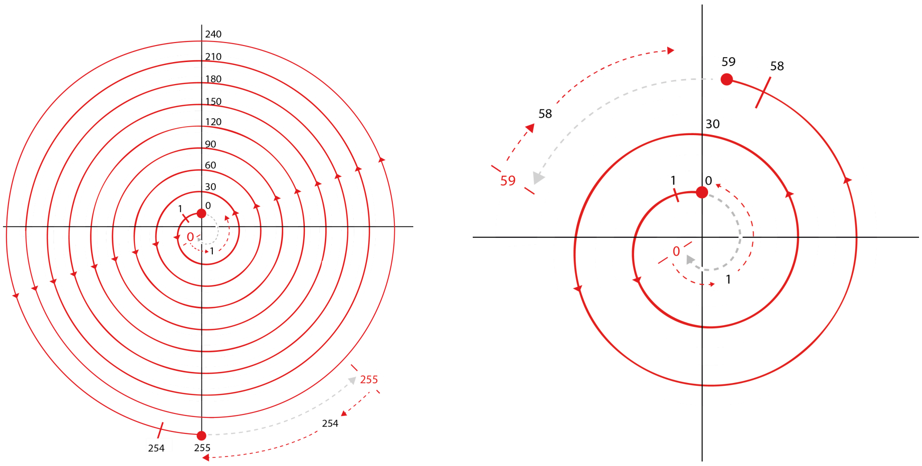
We mount the sensor to the handle to directly capture the cranking movement. Considering the size balance between the sensor and the handle, a 6 cm crank handle was created with 3D printing to fit the chosen rotary encoder (Figure 5). Due to its small and lightweight structure, one hand turns the crank handle, while the other grabs the plane of the sensor for stable control. The sensor mechanism locks the crank handle in position when released. Together they indicate there is no inertia in the form.



< Figure 5. The crank (left) and the setup with the light (right) >

2) Translation

Now we explain how we will translate the cranking input to the light output in **Dis-HANDLE.** For the **CD** setup, we implement a setup where one can obtain an intended value by turning the handle multiple times. Considering the multiple handle turns, we clip the value to clarify the extremes because the sensor has no physical stop against continuous cranking input. For the interaction purpose, the light promptly updates the value when the cranking direction shifts, so the start and end points of a handle turn are relative to where the user left off, as visualised in Figure 6. By contrast, in the **SP** setup, the cranking speed refers to the elapsed time between the current and the previous sensor's position. The value is clipped to map the speed range into the corresponding value range for the light.



< Figure 6. From left to right. Cranking direction: Sensor Behaviour 'Brightness & Colour' and 'Movement' >

Table 1 shows an overview of the implementations, and its details will be explained in the following sections.

Chapter Dis-HANDLE		
Input form	**Setup (Range, Clip/Wrap, Light attribute)**	**Description**
CD	0…255 - Clip - Brightness	Bright (CW) - Dark (ACW)
	0…255 - Clip - Colour (Hue)	Red to Purple (CW) - Purple to Red (ACW)
	0…59 - Clip - Movement	Increment (CW) - Decrement (ACW)
SP	0…255 - Clip - Brightness	Low brightness (slow speed) - High brightness (fast speed)
	0…180 - Clip - Colour (Hue)	Blue (slow speed) - Red (fast speed)
		*Clockwise (CW), Anti-clockwise (ACW)

< Table 1. Overview: Translation between the input and the output (Dis-HANDLE) >

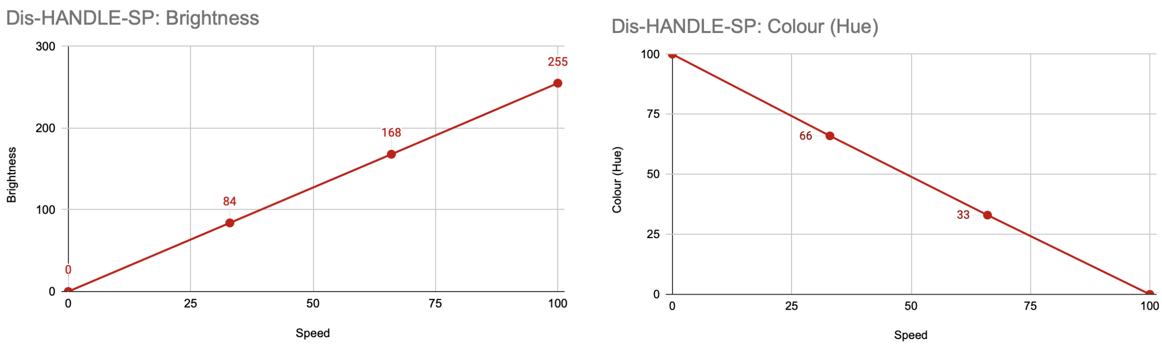
Dis-HANDLE - CD
We simulated a behaviour where a clockwise handle movement increases the value by 1 in the light system, while an anti-clockwise handle movement decreases it by 1; one pulse corresponds to one unit of the light value. We aim to examine how we obtain an intended value by turning the small crank handle multiple times, how we experience the clipped value range and how we experience the relative form of control.

Dis-HANDLE - CD - 0…255 - Clip - Brightness simulates increasing or decreasing the intensity of the brightness by changing the cranking direction. The input value is mapped into the value 0-255 for the brightness level. The minimum and the maximum brightness levels are represented in the clipped value range.

Dis-HANDLE - CD - 0…255 - Clip - Colour (Hue) obtains the hue value ranging from 0 to 255 by shifting the cranking direction. We clip the value to simulate the linear colour spectrum where the start and the endpoints are defined.

Dis-HANDLE - CD - 0…59 - Clip - Movement simulates a behaviour where 1 pulse from a clockwise handle turn moves the single light pixel's position to the next one and vice versa. The value range is clipped to ensure the light moves only within the LED strip.

Dis-HANDLE - SP
Fast cranking is commonly associated with producing higher values, such as the fast winding of a *music box* or the power generation in an *old telephone*. By contrast, slow cranking is often associated with lower values, referring to slower system responses. Given ideas from this, the implementation in **Dis-HANDLE - SP** translates the cranking speed from 0 (slow) to 100 (fast) into the value for each light attribute, as shown in Figure 7. We exclude applying the direction of the speed for the brightness control and the colour control because those values inherently are presented as non-negative values. From this implementation, we aim to examine how we obtain an intended value by turning the small crank handle at different cranking speeds. Here we note two things in our approach. Firstly, the brightness control and the colour control have an unintentional flaw in the code where the light updates only when there is a change in the encoder's position, although this will be fixed after this chapter. Secondly, **Dis-HANDLE - SP** excludes the speed-based movement control since the input-output connection- fast cranking changes the position faster and slow cranking changes it slower- feels repetitive as **Dis-HANDLE - CD - 0…59 - Clip - Movement.**



< Figure 7. From left to right. Mapping: Speed and ‘Brightness’ and ‘Colour’ (Dis-HANDLE) >

Dis-HANDLE - SP - 0…255 - Clip - Brightness simulates the brightness control depending on how fast we crank by mapping the rotational speed (0-100) into the intensity of the brightness level (0-255).

Dis-HANDLE - SP - 0…180 - Clip - Colour maps the rotational speed (0-100) into the hue value in the light display, covering red to blue (0-180). Since 255 (violet) can look similar to 0 (red) during fast cranking, we clip the maximum value range at 180 (blue) to make the extremes of the value more perceptible. For the light output, we reverse the colour spectrum- red for the fast rotation, and blue for the slow as red often represents power and energy, while blue represents a calming impression (Briki & Hue, 2016; Mentzel et al., 2017). Along with the main focus on obtaining value from cranking, we will further examine how the reversed colour range influences the experience.

3) Evaluation: Controllability, Repeatability, Understandability, Intuitiveness, and Engagement

Table 2 illustrates the evaluation of the experiments conducted in **Dis-HANDLE**. The experiences were evaluated with the criteria mentioned in Chapter 2.2. Approaches.

Title: Dis-HANDLE						
Input forms	**Setup**	**Evaluation Criteria**				
		Controllability	**Repeatability**	**Understandability**	**Intuitiveness**	**Engagement**
CD	0…255 - Clip - Brightness	-	++	+	-	-
	0…255 - Clip - Colour (Hue)	+/-	++	++	++	+
	0…59 - Clip - Movement	+/-	++	++	++	+
SP	0…255 - Clip - Brightness	-	+/-	+/-	-	-
	0…180 - Clip - Colour (Hue)	- -	- -	-	- -	- -
						* - - (Bad), -, +/-, +, ++ (Good)

< Table 2. Overview: Evaluation (Dis-HANDLE) >

Dis-HANDLE - CD - 0…255 - Clip - Brightness The absence of inertia in the crank handle allowed changing the cranking direction immediately. The implementation was repeatable due to the familiarity with the common crank-based items where we turned the handle clockwise or anticlockwise to operate. The implementation was understandable because it was easy to observe the influence of the input by updating the value at a small scale. When shifting the cranking direction at the limit, it felt intuitive to observe the light display immediately updated without requiring us to crank back multiple times. However, the clipped range did not match with the concept of cranking, which often allows continuous handle turns in the same direction. This led us to consider wrapping the value, which will be implemented in **Con-HANDLE - CD - 0…255 - Wrap - Brightness** and **Con-GRINDER - CD - 0…255 - Wrap - Brightness.** This implementation did not feel very engaging because we had to reverse the cranking direction at the value limit, which does not fit the continuous movement of cranking.

Dis-HANDLE - CD - 0…255 - Clip - Colour (Hue) One can change the cranking direction promptly because the handle does not have inertia, which is beneficial when encountering the value limit. The implementation was easy to remember because of our familiarity with the interaction updating the value with the clockwise or anticlockwise turns. It was easy to understand because it implemented the colour spectrum that we are familiar with. However, it felt less intuitive because the clipped value range did not match with the concept of the cranking where continuous rotation in the same direction is allowed. For those who are more familiar with a continuous hue cycle, this did not align with their expectations. When cranking back due to the clipped value, it felt that there was a hidden block against the input, which made the setup less engaging. Drawing ideas from the remarks, we will wrap the value to implement the hue's cyclic pattern in **Dis-GRINDER - CD - 0…255 - Wrap - Colour (Hue)**.

Dis-HANDLE- CD - 0…59 - Clip - Movement As the handle does not have inertia, it was easy to change the cranking direction promptly while turning it. With the familiarity with turning the handle clockwise or anticlockwise, it was easy to repeat. As each handle turn updated the light's position at a small scale by turning the handle multiple times, it was easy to understand how the input influenced the output. It was intuitive to observe the light moving in light with the cranking direction and the system tracking the change of the cranking direction. However, we expected the light to continuously move along the strip, rather than being stuck at the clipped value. The mismatch between the input movement and the visual output and the impression that the system limited our movement provided low engagement. From there, we chose to wrap the value in the next experiments so that the cranking input continuously influences the light display. After that, we will examine how wrapping the value influences the experience. This will be shown in **Dis-GRINDER - CD - 0…59 - Wrap - Movement**.

Dis-HANDLE - SP- 0…255 - Clip - Brightness This implementation was not easy to control as it struggled to maintain a consistent cranking speed, especially during fast cranking. The handle does not have inertia, and its size is small compared to our hands. The interaction was easy to repeat since the overall concept reminded us of a dynamo-based camping light. This familiarity enabled achieving high understandability. It was intuitive to see the slow cranking speed provided a low intensity of the value, while the fast cranking speed provided a higher value. It matches our expectation that faster action results in a more pronounced effect. The brightness remained unchanged when the speed was 0, but this is resolved in **Dis-GRINDER - CD - 0…255 - Wrap - Colour (hue).** Although it provided a simulation of the dynamo-based camping light, the difficulty in controllability resulted in flickering lights, making it difficult to be fully engaged with the interaction. Considering these remarks, Chapter 3.2. Grinding Wheel (**Dis-GRINDER**) will use a crank handle that has a larger mass and significant inertia, enabling a more consistent speed control.

Dis-HANDLE - SP - 0…180 - Clip - Colour Without inertia in the handle, it was difficult to maintain a consistent speed, particularly at a fast speed. Repeatability was limited due to the difficulty in speed control, but the associations in the colours and their meanings helped produce blue lights from cranking. It was easy to grasp the output from the slow cranking speed, whereas it was difficult to understand the output from the fast cranking speed where we observed flickering lights with a wide range of hue values. The implemented colour spectrum felt intuitive. A slow cranking represents a calm, which is often shown with blue hues, while a fast cranking is associated with a fast or energetic atmosphere, which is commonly represented in red hues. Considering this, we will continue to implement this colour spectrum for the rest of the study. The light that did not track zero cranking speed will be addressed in **Dis-GRINDER - SP - 0…180 - Clip - Colour**. The light display felt arbitrary during the fast cranking, illustrating the cranking input could not control the lighting system, resulting in low engagement. To resolve the issues, a larger mass of the handle will be involved to make the speed control more stable with its rotational inertia.

4) Discussion and Conclusion

Overall, the simulated behaviours in **Dis-HANDLE** illustrated how the small crank handle influenced obtaining an intended value. In the **CD** setup, the absence of inertia in the handle facilitates prompt changes in the cranking direction. Turning the handle multiple times can help us to understand the influence of cranking by updating the value at a small scale, although it is unclear how many extra turns have been made because the handle position does not correspond directly to the value. As mentioned in **Dis-HANDLE - CD - 0…255 - Clip - Brightness** and **Dis-HANDLE - CD - 0…255 - Clip - Colour (Hue),** clipping the value clarifies the extremes of the value range, but it can also limit the continuous rotational input. In the **SP** setup, the handle feels relatively small to our hand to securely grab and it struggles to maintain a consistent speed, particularly at a fast speed, due to the absence of inertia. This made it difficult to clearly understand what the input generates. Now we compare experiences controlling each light attribute. For the brightness control, the **CD** setup achieved higher controllability, but clipping the value limited the experience, making it feel like turning a knob, instead of cranking. Despite the difficulty in controllability, the **SP** setup's implementation holds potential as an engaging experience by representing a dynamo-based camping light. For the colour control, the clipped range in the **CD** setup does not match our expectation of experiencing the hue's cyclic pattern. The low controllability in the **SP** setup resulted in a less clear input-output connection, particularly in the fast cranking speed. Yet, the reversed value range- fast cranking speed for the low hue value, whereas slow cranking speed for the high hue value- facilitated us to understand the interaction. The movement control will exclude a comparison because the **SP** setup did not implement it. With the common association of faster cranking with faster responses and slower cranking with slower responses, both setups felt similar. However, we later implement the speed-based movement control that will be introduced in the following chapters- **Dis-GRINDER - SP - 0…59 - Wrap - Movement** and **Con-HANDLE - SP - 0…59 - Wrap - Movement**.

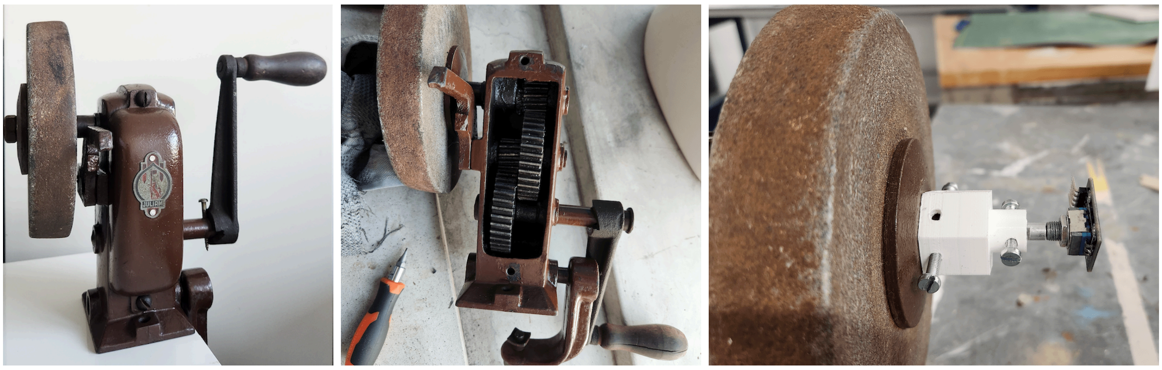
To sum up, the small crank handle is more useful in the **CD** setup than the **SP** setup because of its absence of inertia, and clipping the value can limit the experience from the continuous rotational input. Reflecting on this, the next chapter will use a bigger crank handle that compensates for the inertia and will wrap the values so that we can explore how we translate the characteristics of the revised crank handle into a controllable input and how the experiences differ between clip and wrap.

3.2. Grinding Wheel (Dis-GRINDER)

In the previous chapter **Dis-HANDLE**, we created a simple form of control by using the discrete sensor mounted with a small crank handle, but the small crank handle that does not have inertia can feel difficult to control the input, particularly the speed, suggesting the need of using an enlarged form of control. In this chapter 3.2. Grinding Wheel (this will be referred to as **Dis-GRINDER** from now on), we will repeat the experiments with a grinding wheel that has a greater mass and an evident rotational inertia as a crank input (Figure 8). We specifically chose this grinding wheel because of its high inertia which is not commonly found in crank-based artefacts, and we are interested in how the inertia can influence obtaining a value. Considering the importance of understanding the input's physical behaviours when creating an interaction (Lenz et al, 2014; Wensveen et al, 2004), we will first begin with understanding the grinding wheel's mechanism. After that, we implement the same behaviour as **Dis-HANDLE** in the grinding wheel setups.

1) The form

Originally, this item sharpens knives and other tools through the attached stone. One full turn of the crank handle produces nine rotations of the grinding wheel (this will be referred to as the *1:9 gear ratio* from now on). When the handle is released, the friction from the tooth of each gear gradually slows down the rotation of the wheel. Since it is difficult to install the sensor near the crank handle to capture the cranking input due to the structure of the form and its material, we attached a 3D-printed component that connects the sensor to the grinding wheel (Figure 8).



< Figure 8. From left to right. The crank, the gear system, and the crank with the 3D printed component >

2) Translation

Now we will explain how we translate the cranking input from the grinding wheel into the light in **Dis-GRINDER**. The **Dis-GRINDER-CD** setup simulates the same behaviours as **Dis-HANDLE** to compare the experience in obtaining an intended value- multiple handle turns are required to achieve the maximum value, and the value changes immediately when the cranking direction shifts. On the other hand, in the **Dis-GRINDER-SP** setup, we use the same code as **Dis-HANDLE-SP** to examine how the grinding wheel influences controlling the cranking speed. Table 3 shows an overview of the implementations, which will be further explained in the following pages.

<table>
<tr><td colspan="3">Chapter Dis-GRINDER</td><td></td></tr>
<tr><td>Input form</td><td>Setup</td><td>Description</td><td>Details</td></tr>
<tr><td rowspan="9">CD</td><td rowspan="2">0…255 - Clip - Brightness</td><td rowspan="2">Bright (CW) - Dark (ACW)</td><td>(a) no scale factor</td></tr>
<tr><td>(b) scale factor 1/9</td></tr>
<tr><td rowspan="2">0…255 - Wrap - Colour (Hue)</td><td rowspan="2">Increment (CW) - Decrement (ACW)</td><td>(a) no scale factor</td></tr>
<tr><td>(b) scale factor 1/9</td></tr>
<tr><td rowspan="2">0…255 - Clip - Colour (Saturation)</td><td rowspan="2">White to Red (CW) - Red to White (ACW)</td><td>(a) no scale factor</td></tr>
<tr><td>(b) scale factor 1/9</td></tr>
<tr><td rowspan="3">0…59 - Wrap - Movement</td><td rowspan="3">Increment (CW) - Decrement (ACW)</td><td>(a) no scale factor</td></tr>
<tr><td>(b) scale factor 1/9</td></tr>
<tr><td>(b) scale factor 1/3</td></tr>
<tr><td rowspan="3">SP</td><td>0…255 - Clip - Brightness</td><td>Dark (slow) - Bright (fast)</td><td>-</td></tr>
<tr><td>0…180 - Clip - Colour</td><td>Blue (slow) - Red (fast)</td><td>-</td></tr>
<tr><td>0…59 - Wrap - Movement</td><td>Decelerator (slow) - Accelerator (fast)</td><td>-</td></tr>
<tr><td colspan="4" align="right">*Clockwise (CW), Anti-clockwise (ACW)</td></tr>
</table>

< Table 3. Overview: Translation between the input and the output (Dis-GRINDER)>

Dis-GRINDER - CD

We implemented a clockwise handle turn that increases the value, whereas the anticlockwise movement decreases it. In this approach, we are interested in how the grinding wheel's high inertia influences changing cranking directions. There are three updates in our approach for **Dis-GRINDER - CD**. Firstly, certain setups scale down the measured value from the sensor corresponding to the 1:9 gear ratio for the interaction purpose (This step will be referred to as *applying scale factor* from now on). Considering the 1:9 gear ratio of the grinding wheel, one full handle turn can produce 270 pulses from the sensor, which can reach the maximum or the minimum output immediately. This led us to execute two comparable setups- (1) where one full handle turn directly applies to the output and (2) where it applies the scale factor 1/9. Secondly, the colour control in **Dis-GRINDER - CD** covers both a hue control and a saturation control. Since saturation refers to the intensity and vibrancy of the colours (Ware, 2013), it is relevant to include saturation transition in the colour control in this study and examine its experience. Each setup will be specified in its name as 'the colour (hue)' and 'the colour (saturation)'. Lastly, based on the remarks from **Dis-HANDLE**, we wrap the value to simulate the hue cycle for the colour control (hue) and the movement that follows along the loop structure of the LED strip the movement control. The brightness control remains to clip the value. The following illustrates each setup in more detail.

Dis-GRINDER - CD - 0…255 - Clip - Brightness simulates controlling the intensity of the brightness by shifting the cranking direction in two setups - **(a)** no scale factor and **(b)** scale factor 1/9. This setup aims to examine how the grinding wheel's high inertia influences our control within this clipped value range in the brightness control.

(a) no scale factor: It uses the code from **Dis-HANDLE - CD - 0…255 - Clip - Brightness**, where each pulse from the sensor corresponds to 1 unit of the value and is mapped to the brightness range (0-255).

(b) scale factor 1/9: It applies a scaling factor of 1/9 given ideas from the 1:9 gear ratio; 9 pulses are required to update the brightness value by 1. It simulates the behaviour implemented in **Dis-HANDLE - CD - 0…255 - Clip - Brightness.**

Dis-GRINDER - CD - 0…255 - Wrap - Colour (hue) simulates controlling the entire hue range (0-255) in the HSB system by shifting the cranking direction in two setups - **(a)** no scale factor and **(b)** scale factor 1/9**.** Through this setup, we aim to examine how we experience turning the handle with significant inertia multiple times to reach a value in the hue cycle, which is often represented in one cycle.

(a) no scale factor: It updates the hue value by 1 with each pulse from the sensor. It uses the code from **Dis-HANDLE - CD - 0…255 - Clip - Colour (Hue)** but is controlled by the grinding wheel.

(b) scale factor 1/9: By applying the scale factor, it simulates a behaviour where 9 encoder steps update the hue value by 1 to repeat the experience from **Dis-HANDLE - CD - 0…255 - Clip - Colour (Hue).**

Dis-GRINDER - CD - 0…255 - Clip - Colour (saturation) controls the saturation value (0-255) in the HSB system by shifting the cranking direction. The hue value is fixed to 0 (red). To keep the experiment setup coherent as other light attributes, we created two setups - **(a)** no scale factor and **(b)** scale factor 1/9. We are interested in exploring how we control the saturation value represented in a clipped range by turning the handle with high inertia.

(a) no scale factor: Without the application of the scale factor, each pulse from the sensor updates the saturation value by 1 in the clipped range.

(b) scale factor 1/9: This setup updates the saturation value by 1 with 9 encoder steps with the application of the scale factor 1/9.

Dis-GRINDER - CD - 0…59 - Wrap - Movement simulates moving a single pixel of the light along the LED structure by changing the cranking direction in three setups- **(a)** no scale factor, **(b)** scale factor 1/9 and **(c)** scale factor 1/3**.** When the input value reaches the last pixel of the light strip, it wraps it back to the first pixel and vice versa to align the rotational input behaviour with the loop structure of the light, given ideas from **Dis-HANDLE - CD - 0…59 -Clip - Movement.**

(a) no scale factor: It simulates one pulse from the sensor updating the light's position by 1. It uses the code from **Dis-HANDLE - CD - 0…59 -Clip - Movement.**

(b) scale factor 1/9: With the application of the scale factor, 9 pulses from the sensor update the light's position by 1 to simulate the same behaviour as **Dis-HANDLE - CD - 0…59 -Clip - Movement.**

(c) scale factor 1/3: 3 pulses from the sensor updates the light's position by 1. Here we note that the **(c)** setup was conducted after experimenting with the aforementioned set-ups; we observed the interaction in **(a)** was too fast and **(b)** was too slow. By conducting these experiments, we aim to compare the experience across different scaling approaches.

Dis-GRINDER - SP

The grinding wheel's handle size, mass and inertia can achieve a faster speed, but the speed range remains the same - 0 (slow speed) to 100 (fast speed) - to compare how the grinding wheel's handle differs from the small crank handle when obtaining a value. A faster speed indicates a smaller time interval between pulses, while a slower speed corresponds to a larger time interval. Throughout the implementations, we will pay attention to how the grinding wheel, particularly its high inertia, influences controlling the cranking speed. There are two things to note regarding our approach in **Dis-GRINDER-SP.** Firstly, now the brightness control and the colour control track the zero speed of cranking, which **Dis-HANDLE-SP** mentioned as an unintentional flaw**.** The code gradually dims the light if there is no cranking input within 500 milliseconds. Secondly, this chapter implements a speed-based movement control, which was not conducted in **Dis-HANDLE.** Unlike the two other light attributes where the interaction depends on the user's input, the movement control simulates where the cranking speed influences the light's behaviour; the light has autonomy. Its detailed description will be shown in the movement control section.

Dis-GRINDER - SP- 0…255 - Clip - Brightness maps the cranking speed (0-100) to the brightness range from 0 (low brightness) to 255 (high brightness). We used the code from **Dis-HANDLE - SP-0…255 - Clip - Brightness** to examine how turning the grinding wheel can achieve an intended value compared to when turning the small crank handle.

Dis-GRINDER - SP - 0…180 - Clip - Colour (Hue) maps the cranking speed (0-100) into blue light (180) to red light (0) with the same motivation mentioned in **Dis-HANDLE - SP - 0…180 - Clip - Colour**: the association of the colours with its meanings. The hue value range is clipped until 180 to visually clarify the start and end points of the light display.

Dis-GRINDER - SP - 0…59 - Wrap - Movement maps the cranking speed to the acceleration or deceleration of a single light pixel moving along the LED strip. By default, the pixel's position is updated every 10 milliseconds to simulate its movement. On top of this implementation, the cranking speed is translated into the rate at which the pixel moves. In this setup, cranking direction does not influence the controlled light's direction, although speed inherently has polarity. This is because we want the pixel's movement to represent only the magnitude of the cranking speed so that we can focus on the controllability of the grinding wheel's crank handle in this implementation. This is implemented by abs(speed) in the code.

3) Evaluation: Controllability, Repeatability, Understandability, Intuitiveness, and Engagement

Table 4 illustrates the evaluation of the experiments conducted in **Dis-GRINDER**.

Title: Dis-GRINDER							
Input form	**Setup**	**Details**	**Evaluation Criteria**				
			Controllability	**Repeatability**	**Understandability**	**Intuitiveness**	**Engagement**
CD	0…255 - Clip - Brightness	(a) no scale factor	- -	- -	- -	- -	- -
		(b) scale factor 1/9	+/-	+/-	+	+/-	+/-
	0…255- Wrap - Colour (Hue)	(a) no scale factor	- -	- -	- -	- -	- -
		(b) scale factor 1/9	+/-	+	+/-	+	+
	0…255 - Clip - Colour (Saturation)	(a) no scale factor	- -	-	- -	- -	- -
		(b) scale factor 1/9	+/-	+/-	-	-	- -
	0…59 - Wrap - Movement	(a) no scale factor	- -	- -	- -	- -	-
		(b) scale factor 1/9	+/-	+/-	+	+	+/-
		(b) scale factor 1/3	+	+	+	+	+
SP	0…255 - Clip - Brightness		+/-	+	+	+	+
	0…180 - Clip - Colour		+/-	-	+	-	-
	0…59 - Wrap - Movement		+	+/-	+	+/-	++
* - - (Bad), -, +/-, +, ++ (Good)							

< Table 4. Overview: Evaluation (Dis-GRINDER) >

Dis-GRINDER - CD - 0…255 - Clip - Brightness It simulates where the cranking direction controls the limited value range throughout the two experiments- **(a)** no scale factor and **(b)** scale factor 1/9**.**

(a) no scale factor: Without sensor scaling, it did not feel controllable because one handle rotation changed the value rapidly. It was difficult to stop the handle due to the grinding wheel's high inertia. The interaction was not very repeatable because it was difficult to understand why it caused such a rapid change from the user's perspective. Intuitiveness was low. We expected the system to respond slower, considering the size of the grinding wheel and how we often interact with the handle that has a larger circumference and a bigger mass. As the whole interaction was completed so quickly that our input did not have full control over the system, it felt difficult to be fully engaged.

(b) Scale factor 1/9: The grinding wheel's high inertia introduced difficulties in making a sudden change when encountering the value limit. With the familiarity with the interaction- a clockwise turn and an anti-clockwise turn, the interaction felt easy to repeat. Sensor scaling allowed simulating the same behaviour as **Dis-HANDLE - CD - 0…255 - Clip - Brightness.** This enhanced understandability regarding what the input generates as an output. The implementation achieved low intuitiveness since clipping the value did not match well with the continuous cranking movement. This led us to consider wrapping the value in the brightness control setup. The implementation achieved high engagement by simulating how we make the light brighter or dimmer by turning the handle, however, the implementation required significant efforts to accomplish the maximum brightness level, which may not be entirely engaging to experience.

Dis-GRINDER - CD - 0…255 - Wrap - Colour (Hue) We implemented a circular form of control to simulate the cyclic pattern of the hue in two experiments- **(a)** no scale factor and **(b)** scale factor 1/9**.**

(a) no scale factor: Without applying the scale factor, one full-handle turn already provided a pronounced effect; the light's colour changed too fast. In this fast transition, the wheel's high inertia hindered us from stopping the handle or changing the cranking direction. The implementation was difficult to repeat because so many value transitions were made, and it was difficult to understand how the crank controls the hue value. The whole interaction did not feel intuitive. The fast value transition did not align with how we commonly turned the handle with a larger circumference and a larger mass; fewer value transitions from one handle turn would align better with this grinding wheel's colour control. As it felt that the system was out of control with one tiny movement from the handle, it was difficult to be fully engaged with.

(b) Scale factor 1/9: The wheel's significant inertia made it difficult to stop cranking in this wrapped value. Wrapping the value reminded us of the cyclic pattern of the hue, which felt easy to repeat with this crank-based control. The scaling factor enabled the simulation of one cycle of value transition controlled by multiple handle turns. It helped us to understand how the input updates the hue value. The value changed not too quickly nor too slowly, and thereby it matched our expectation of turning the handle with a greater mass, However, it was unclear to distinguish how many times to turn to achieve one cycle of the hue transition. As the interaction only provided a simple light display that we can experience from conventional light controllers, we will further explore other ways to enhance its engagement in **4.2. Grinding Wheel (Con-GRINDER).**

Dis-GRINDER - CD - 0…255 - Clip - Colour (Saturation) It simulates the behaviour of the saturation control from turning the handle in two setups- **(a)** no scale factor and **(b)** scale factor 1/9**.**

(a) No scale factor: When observing its fast value transition, the wheel's high inertia made it difficult to stop the handle, however, the system still clearly captured the cranking direction shift. It was repeatable to reverse the cranking direction in this clipped value range because we were aiming to see the value update while cranking. However, the overall experience was not very repeatable. It was difficult to understand how the input controls the output and why the red light was being shown; observing a fast transition from white to red and vice versa felt arbitrary. The output was shown too fast from a tiny input, making the setup less intuitive. The low engagement was due to the rapid value transition.

(b) Scale factor 1/9: The wheel's significant inertia made it difficult to stop cranking and change the cranking direction when encountering the limit of the clipped value range. The implementation was repeatable because of the simple input behaviour- a clockwise turn and an anticlockwise turn. Applying the scale factor facilitated understanding how the input updated the value. The clipped value was intuitive by prompting us to crank back to update the value. However, observing a saturation transition in the colour control context reduced the intuitiveness of the interaction. It is less common to control only the saturation of the light, and it was unexpected to observe the value transition starting from white to red. Reversing the crank direction constantly in this clipped value range did not match the concept of the crank-based interaction, and thereby it resulted in low engagement. Considering the remarks, updating the saturation value may be less valuable to discovering interesting insights in the **CD** setup for the rest of the study.

Dis-GRINDER - CD - 0…59 - Wrap - Movement It updates the light position within the range in three setups- **(a)** no scale factor, **(b)** scale factor 1/9 and **(c)** scale factor 1/3.

(a) No scale factor: Without applying the scale factor, the light changed its position too fast. Due to the wheel's high inertia, it was difficult to stop the light at its intended position. Repeatability was low due to the fast value transition. Without applying the scale factor, the light was looping at a fast speed, and it was difficult to understand how to position the value from cranking. It resulted in low intuitiveness. Observing the fast transition did not align with our expectations to have a slower response than the current result while turning the handle that has a bigger mass and a larger radius. The output looked so arbitrary that it felt hard to be engaged.

(b) Scale factor 1/9: With the wheel's high inertia, it was not very easy to stop cranking or change its direction to position the light pixel as intended. It was easy to repeat because the cranking direction and the direction of the light's movement matched. By applying the scaling factor, the interaction became more understandable regarding how the input triggers the output. Yet, it was unclear how many handle turns were required to achieve an intended position since the handle position did not correspond to the value. The implementation felt intuitive because the continuous rotational cranking input matched the light's loop structure. It was engaging but it felt physically demanding to turn the handle to change a single pixel of the light, which felt like a minimal visual effect.

(c) Scale factor 1/3: The wheel's high inertia made it difficult to stop cranking or change its direction to put the light in the intended position. However, the overall interaction was easy to repeat with the same reason mentioned in **(b)** Scale factor 1/9. Although the overall interaction felt understandable, it still felt difficult to grasp how many turns were required to update the light position. It was intuitive to observe the connection between the light's structure, the light's movement and the cranking movement. Also, the system responded not too fast nor not too slow. As it felt that we were in good control over the light, we were easily able to engage with the experience.

Dis-GRINDER - SP- 0…255 - Clip - Brightness It felt easier to make a consistent cranking speed due to the high inertia. However, there were difficulties in promptly changing the cranking speed. The overall concept was repeatable as the interaction reminded us of the dynamo-based *camping light* example, which is also linked to achieving high understandability. It felt intuitive that the simulated behaviour reflected the physical nature; the fast speed with high intensity or more power whereas slow speed with low intensity or less power. It was also engaging because it felt easier to control and it represented our mechanical input as the power source for the light.

Dis-GRINDER - SP - 0…180 - Clip - Colour Due to the wheel's inertia, it was difficult to make a sudden speed change, while it could make a consistent cranking input, which was beneficial when cranking at a high speed. The implementation was repeatable by leveraging how we associate the colours and their meaning with speed. This association supported the experience to be understandable and intuitive. It was engaging because it visualised the physical experience with the input into the light's form.

Dis-GRINDER - SP - 0…59 - Wrap - Movement It was difficult to make an immediate speed change due to the wheel's high inertia. Yet, the inertia facilitated making a consistent speed and demonstrating the acceleration. The whole interaction concept was repeatable as it reflected the physical nature of the experience. This further resulted in the high understandability of the experience. Regardless, intuitiveness felt limited, because the speed value immediately dropped to zero when slowing down the cranking speed and the directional speed was not applied. However, this interaction felt engaging. The grinding wheel's high inertia supported cranking continuously, making the whole experience continuous accordingly. From there, we could choose whether to support the light's autonomy or go against it in this implementation.

4) Discussion & Conclusion

Dis-GRINDER showcased how the grinding wheel influenced shifting the cranking direction and controlling the cranking speed. **Dis-GRINDER-CD** illustrated that the application of the scale factor enabled the simulation of the behaviours in **Dis-HANDLE.** Reflecting on the close relationship between intuitiveness and the system response time of the user's input (Wensveen et al, 2004), sensor scaling enhances the intuitiveness of the experience. However, as shown in **Dis-GRINDER - CD - 0…59 - Wrap - Movement - (b)**, the scale factor can be modified to be different from the gear ratio depending on the intention of the experience. Across all the setups, the grinding wheel's high inertia introduces difficulties in changing the cranking direction or stopping the handle, especially when encountering the value limit in the clipped value range setup. In the wrapped value setup, we were prompted to crank in the same direction continuously, and the wheel's inertia supported us to continue cranking. This made the interactions feel more ongoing, as shown in **Dis-GRINDER - CD - 0…255 - Wrap - Colour** and **Dis-GRINDER - SP - 0…59 - Wrap - Movement.** By contrast, in **Dis-GRINDER-SP**, the wheel's high inertia enables producing a consistent cranking speed, which is beneficial to control the input over time, and this further results in providing a more understandable implementation. Now we compare the experiences for each light attribute controlled by the two input forms. For the brightness control, clipping hindered us from continuing cranking. This felt less intuitive to interact with, particularly when the cranking movement was supported by the wheel's high inertia. Yet, the interaction felt more than turning a knob, and thereby engaging because the use of scale factor required more handle turns as well as more physical effort to obtain an intended brightness. On the other hand, the **SP** setup provided a more understandable and engaging output, leveraging from the inertia. The interaction reminded us of a dynamo-based camping light, where consistent cranking input is required as a power source for the light. For the colour control, wrapping was useful in the **CD** setup to simulate a cyclic pattern of the hue, and it aligned well with the continuous rotational input movement. However, it struggled to obtain a value as intended due to the wheel's high inertia, resulting in a minor slip when releasing the handle. Also, it noted that turning the handle multiple times contradicts the hue cycle, which is often completed in one cycle. This can be further associated with the use of relative handle position, which did not inform the corresponding hue value. The high inertia was beneficial in the **SP** setup, making the implementation easier to understand. The use of the reversed colour spectrum for mapping felt intuitive. For movement control, the wheel's inertia facilitated ongoing cranking in the **CD** setup, which wrapped the value range. The translation aligned well with the rotational movement and the light's structure. We further observed that the scale factor can be modified to make the interaction more intuitive; applying the scale factor as the same as the gear ratio made the experience physically demanding compared to the resulting light output. The implementation of the **SP** setup resulted in an engaging setup that has a different approach than the **CD** setup. With the wheel's inertia, cranking speed felt controllable. It was effective in accelerating the light's movement, although it was difficult to decelerate the light. Furthermore, the **SP** setup excluded applying the directional speed, which eventually reduced the intuitiveness of the interaction.

To sum up, we applied the scale factor in **Dis-GRINDER-CD** to simulate a similar experience as **Dis-HANDLE-CD**. By aligning our expectation of turning the bigger handle with the system response, the interaction became more understandable and intuitive, although it can be modified depending on the setup. Overall, **Dis-GRINDER** showed that the grinding wheel's inertia supports providing a consistent cranking input, and it is useful to continue cranking in the same direction in the wrapped value range and to maintain the cranking speed, which is effective in the **SP** setup. However, it can be challenging to make a sudden change in cranking. It is not useful when the value is clipped to position the handle as intended or when prompt speed control is needed. In the following chapter, we will compare the experiences across **Dis-HANDLE** and **Dis-GRINDER** and discuss further approaches.

3.3. Discrete Sensor: Discussion & Conclusion

Chapter 3. Discrete Sensor: Experiments conducted numerous experiments where the discrete rotary encoder was mounted to the small crank handle (**Dis-HANDLE)** or the grinding wheel (**Dis-GRINDER)**. Because of the resolution of the chosen discrete sensor, we compensated for the limited amount of 30 pulses per rotation by requiring multiple turns to change a value in steps of 1 from 0 to for example 255. The values were clipped at their respective minimum and maximum and immediately changed value in case the rotational direction shifted; the handle's position was relative. Now we will cross-evaluate the use of the discrete sensor of the cranking direction (**CD**) and the cranking speed (**SP**) controlled by the cranking handle (**HANDLE**) or the grinding wheel (**GRINDER**). Our objective is to compare the options that share commonalities, such as the utilised form factors (**HANDLE** or **GRINDER)** or the input forms (**CD** or **SP)**, and those are as follows- (1) **Dis-HANDLE-CD & Dis-HANDLE-SP.** (2) **Dis-GRINDER-CD & Dis-GRINDER-SP,** (3) **Dis-HANDLE-CD & Dis-GRINDER-CD** and (4) **Dis-HANDLE-SP & Dis-GRINDER-SP.** We do not compare the setups where it controlled the light with different form factors and different input forms, such as **Dis-HANDLE-CD & Dis-GRINDER-SP** and **Dis-GRINDER-CD & Dis-HANDLE-SP.** After that, we conclude by suggesting further directions we will take in the next chapter.

1) Dis-HANDLE-CD & Dis-HANDLE-SP

We compare the setups controlled by the small crank handle with different input forms (**CD** and **SP**) and both illustrate the influence of the small crank handle and the use of the clipped value range. Due to the absence of inertia in the handle, one can easily stop the handle or change its direction. This is useful in the **Dis-HANDLE-CD** where one has to shift the crank direction at the value limit. On the other hand, in **Dis-HANDLE-SP,** it is difficult to achieve a fast speed and control the speed value with the small crank handle, because the crank handle is relatively small for our hand to grab securely and it does not have inertia to support cranking constantly. This illustrates the small crank handle by turning multiple turns can support obtaining an intended value in the **CD** setup, while turning the small handle is difficult to control in the **SP** setup.

2) Dis-GRINDER-CD & Dis-GRINDER-SP

Now we compare the setups with the grinding wheel but use different input forms (**CD** and **SP**) to show how the wheel's high inertia influences obtaining the value. In **Dis-GRINDER-CD** where the value range is clipped, the wheel's higher inertia makes it difficult to stop the handle or change the cranking direction, particularly when we crank back at the value limit to see the value change. The inertia makes the clipped value range against our tendency to continue cranking in the same direction once we start turning the handle. In **Dis-GRINDER-SP**, high inertia facilitates making a more consistent rotational input, and it further makes the overall concept of the translation more understandable, as mentioned in **Dis-GRINDER - SP- 0…255 - Clip - Brightness** and **Dis-GRINDER - SP - 0…180 - Clip - Colour.** Yet, controlling the speed within the high inertia makes it difficult to simulate the deceleration of the light, as shown in **Dis-GRINDER - SP - 0…59 - Wrap - Movement.** From this comparison, we observe that the wheel's high inertia makes the **CD** setup less controllable to position the crank handle as intended to achieve a certain value. By contrast, the **SP** setup leverages the inertia, making the speed input to be constant and thereby more controllable.

3) Dis-HANDLE-CD & Dis-GRINDER-CD

The following compares the **CD** setups controlled by the small crank handle **(Dis-HANDLE-CD)** or the grinding wheel (**Dis-GRINDER-CD)**. For both, one can observe and easily understand the impact of the cranking input by turning the handle multiple times. For the grinding wheel setup, the use of scale factor enables us to simulate the same behaviour- turning the handle almost 9 times to reach the maximum value. The small crank handle that does not have inertia feels more controllable when changing the cranking direction, which is particularly beneficial in the clipped value range. On the other hand, the wheel's high inertia struggles to stop cranking or promptly change its direction, making the setups less controllable especially when the value is clipped. Whereas, when the value is wrapped, the inertia facilitates constantly turning the handle to reach the extremes of the value. The simulated setup becomes more aligned with our continuous input movement, making the experience more intuitive. Both **Dis-HANDLE-CD** and **Dis-GRINDER-CD** use the relative handle position, which clarifies the value limit, while it is difficult to know which value the cranking obtained and how many more turns to make to reach the maximum or the minimum while cranking. These findings show that the small crank handle can be more useful in making a sudden change in the cranking direction, particularly when the value range is clipped. The grinding wheel struggles to promptly position the handle as intended due to its high inertia, but it can be useful to make the interaction more intuitive when the value is wrapped.

4) Dis-HANDLE-SP & Dis-GRINDER-SP

Now we compare the **SP** setups controlled by the small crank handle **(Dis-HANDLE-SP)** or the grinding wheel (**Dis-GRINDER-SP).** In **Dis-HANDLE-SP,** one struggles to the consistent rotational speed due to its small size and the absence of inertia, leading to a less understandable output, as shown in **Dis-HANDLE - SP - 0…255 - Clip - Brightness** and **Dis-HANDLE - SP - 0…180 - Clip - Colour.** By contrast, with its enlarged form, the grinding wheel's high inertia facilitates controlling the speed and reaching a higher speed, enabling a more understandable experience, as shown in **Dis-GRINDER - SP- 0…255 - Clip - Brightness** and **Dis-GRINDER - SP - 0…180 - Clip - Colour.** This showcases that the grinding wheel is more effective in controlling the speed compared to the small crank handle, particularly with its inertia.

So far, we have compared the setups where the discrete sensor is mounted to the small crank handle or the grinding wheel and the findings show different influences from the crank handles' characteristics and how it works with the given value range. Based on the collected remarks, we will update our approach in the next chapters as follows. Firstly, up to this point, we only used the discrete rotary encoder that can only provide 30 pulses per rotation and simulated the relative handle position. When the value is wrapped, it is unclear how many turns are needed to achieve the maximum and the minimum value while cranking as the handle position does not correspond to the value. From there, we become curious about the experience with one full-handle turn that corresponds to the entire value range by using a continuous sensor that contains a higher resolution per sensor. Secondly, from now on, all the light attributes controlled within the **CD** setups will wrap the values because wrapping the value can align with our continuous rotational input, leading to a more intuitive interaction. Lastly, we will continue exploring the simulated behaviour in **Dis-GRINDER - SP - 0…59 - Wrap - Movement** and more in different setups. Unlike other simulations aiming to create a direct form of control, this simulation showcases that light influences our behaviour, and it aligns with another aim of the study-creating an interactive dialogue. With that, the next chapter will explain how we update the setup to address the aspects discussed.

4. Continuous Sensor: Experiments

In this chapter, we repeat the experiments in which the handle is directly mounted to the sensor and the setup in which the sensor is mounted to the grinding wheel. We are going to do comparable experiments to Chapter 3 but we replace the used rotary encoder with a 360-degree continuous potentiometer that allows us to use a single rotation to create the full range, depending on the light attribute to control- 0-255 (brightness in the **CD** and **SP** setups and hue in the **CD** setup), 0-59 (movement in the **CD** and **SP** setups), 0-180 (hue in the **SP** setup). We are interested in using the absolute position of the crankle handle as a value as opposed to the relative position used in the **Dis-HANDLE** experiments. To realise this, we decided to use a 360-degree continuous potentiometer (RV112FF-40) given Baalman's (2022) suggested list of criteria (intended use, technical capability and availability). The continuous sensor has two separate tapers that provide a sine and a cosine function. The values of the two tapers are connected to the analogue inputs of the Arduino with a resolution of 10 bits each. In the code, the corresponding angle of the encoder axis is calculated using an atan2 function. The resulting resolution is higher than a single degree. Now we have more than enough angular resolution to use the angular value of only one rotation to control the desired output. Furthermore, the use of the position has become absolute as intended. The absolute nature of the sensor eliminates the accumulative approach used in **Dis-HANDLE** and therefore the angular value is persistent and reboot-proof. The input values from cranking are 'float' variables for higher precision, while the output value is used in 'int' variables. This allows for avoiding rounding the values when using integers. The following shows the use of each input form in this chapter.

- **Cranking direction (clockwise/anti-clockwise)**: The sensor tracks changes in the handle's angular position, resulting in increments by one and decrements by one; A single rotation corresponds to the full range. The following pages will refer to this input form as **CD**.

- **Speed (fast/slow)**: We measure the difference between the current and the previous angular positions of the sensor during 100 milliseconds of the fixed intervals. The value ranges from 0 to 180. We clipped the value until 180, which can be achieved effectively with the utilised handle. We call this **SP** on the following pages.

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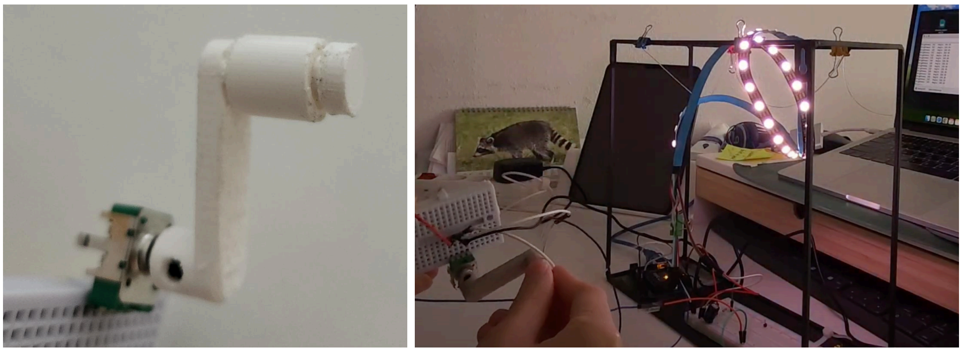
4.1. Crank Handle (Con-HANDLE)

This chapter uses the 360-degree continuous potentiometer to implement the 360-degree-based nature with the full range of the cranking movement. By executing comparable experiments as **Dis-HANDLE**, we aim to examine the handle's absolute angular position regarding the translation process and the interaction**.** To focus on examining the sensor and implementing the direct form of control, creating an interactive dialogue is not fully addressed in this chapter. The title of the chapter will be referred to as **Con-HANDLE** in the following pages.

1) The form

Con-HANDLE uses a 3D-printed, 6 cm-sized crank handle which fits the sensor (Figure 9). To make a direct comparison between the discrete sensor and the continuous sensor, we kept a simple setup.



< Figure 9. The crank (left) and the setup with the light (right) >

2) Translation

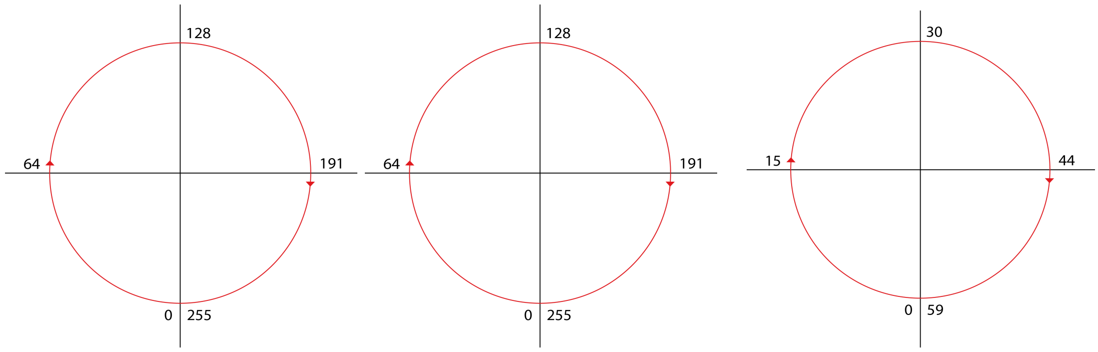
The 360-degree continuous potentiometer provides a value ranging from 0 to 359 per full handle rotation. As this value range corresponds to the natural perception of angular coordinates in a circular system, we chose to repeat the setups by using this absolute form of control as opposed to the relative position used in **Dis-HANDLE**. Particularly for the **CD** setup, the value range (0-359) is mapped into the value range for each light attribute. The **SP** setup remains the same simulation where the speed input is directly mapped into the value for each light attribute. An overview of the implementations (Table 5) and detailed descriptions for each setup will be shown in the following pages.

Chapter Con-HANDLE		
Input form	**Setup (Range, Clip/Wrap, Light attribute)**	**Description**
CD	0…255 - Wrap - Brightness	Bright (CW) - Dark (ACW)
	0…255 - Wrap - Colour (Hue)	Red to Blue (CW) - Blue to Red (ACW)
	0…59 - Wrap - Movement	Increment (CW) - Decrement (ACW)
SP	0…255 - Clip - Brightness	Low brightness (slow) - High brightness (fast)
	0…180 - Clip - Colour (Hue)	Blue (slow) - Red (fast)
	0…59 - Wrap - Movement	Decelerator (slow) - Accelerator (fast)
		*Clockwise (CW), Anti-clockwise (ACW)

< Table 5. Overview: Translation (Con-HANDLE) >

Con-HANDLE - CD

The overall approach remains the same as the previous Chapter 3. Discrete Sensor: Experiments; a clockwise movement increases the value, while an anti-clockwise movement decreases it. Given the ideas from the natural perception of angular coordinates, we intend the handle's angular position in space directly to correspond to the value by mapping the input value (0-359) into the value for each light attribute, as shown in Figure 10. To implement the absolute form of control, we wrap the value so that the cranking value goes back to the minimum value when it reaches the maximum value and vice versa. It is also relevant to wrap the value based on the remarks from **Dis-GRINDER-CD**, pointing out that clipping the value can reduce intuitiveness and engagement of the interaction as it hinders us from turning the handle continuously. In **Con-HANDLE - CD,** we will examine how the absolute reference in a wrapped value range influences controlling the light. The detailed descriptions for each implementation are shown on the following page.



< Figure 10. From left to right. Cranking direction: Sensor Behaviour 'Brightness', 'Colour' and 'Movement' (Con-HANDLE)>

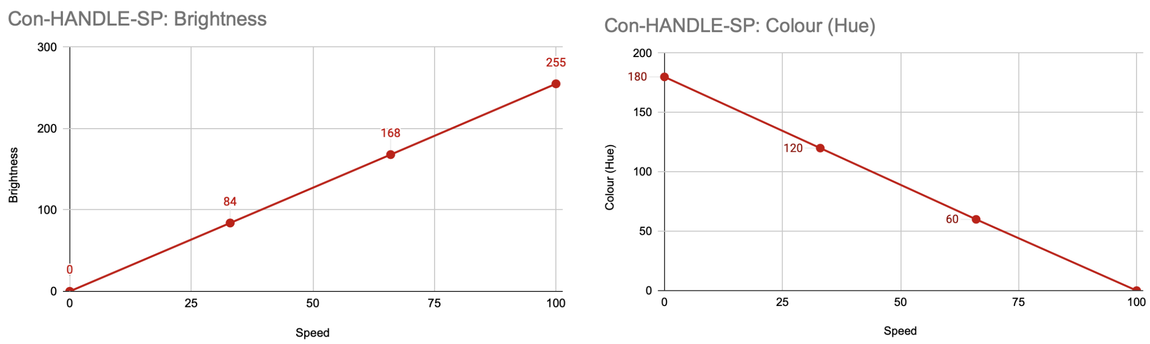
Con-HANDLE - CD - 0…255 - Wrap - Brightness maps the input value (0-359) into the brightness value (0-255). Although wrapping the values can cause an abrupt jump between the extremes, we first aim to compare the experiences between this setup and the setup with the clipped value range **Dis-HANDLE - CD - 0…255 - Clip - Brightness.**

Con-HANDLE - CD - 0…255 - Wrap - Colour (Hue) simulates an interaction where one full handle turn (0-359) reaches the entire hue spectrum (0-255). This approach will be compared with **Dis-HANDLE - CD - 0…255 - Clip - Colour (Hue)** regarding the value range and the numbers of handle turns to reach the extremes and **Dis-GRINDER - CD - 0…255 - Wrap - Colour (hue)** regarding turning crank handles with different physical characteristics.

Con-HANDLE - CD - 0…59 - Wrap - Movement translates the sensor's angular input value (0-359) into the light strip's corresponding positions (indexed 0-59), and each specific angular position lights up the same index of the LED. This aims to examine the difference in the required numbers of the handle turns to reach the maximum compared to **Dis-HANDLE - CD - 0…59 - Clip - Movement** and the difference in the use of different types of the crank handle compared to **Dis-GRINDER - CD - 0…59 - Wrap - Movement.**

Con-HANDLE - SP

The overall translation approach remains the same - a faster cranking speed produces a higher value, while a slower cranking speed produces a lower value. The code calculates the difference between the current and previous angles during the fixed time interval of 100 milliseconds. The speed value ranges from 0 (slow) to 180 (fast), which can be achieved with the current form, and it is mapped into the value range for the brightness and the hue (Figure 11). Although the main logic to measure the speed remains the same, we will focus on obtaining a value within a modified speed range and the movement control that was not discussed in the previous chapters. Here we note that we apply the directional speed in the movement control since the speed has its direction by nature, while the brightness control and the colour control exclude it since it is not logical to apply the negative values to the intensity (brightness) and the type (hue) of the light. The following text will explain our approaches for the three light attributes with the speed-based control in more detail.



< Figure 11. From left to right. Speed: Sensor Behaviour ‘Brightness’ and ‘Colour>

Con-HANDLE - SP - 0…255 - Clip - Brightness translates the speed range 0-180 to the value range 0-255 of the brightness level, and ‘abs(speed)’ in the code captures the magnitude of the speed. This setup aims to examine how the revised handle design can lead to obtaining an intended value compared to **Dis-HANDLE - SP - 0…255 - Clip - Brightness.**

Con-HANDLE - SP - 0…180 - Clip - Colour (Hue) maps the slow speed (0) resulting in blue (255 in hue value), while the fast speed (180) generates red (0 in hue value). When there is no rotational movement, the light gradually dims. This setup aims to examine attaining an intended value compared to **Dis-HANDLE - SP - 0…180 - Clip - Colour (Hue).**

Con-HANDLE - SP - 0…59 - Wrap - Movement simulates a behaviour in which the cranking speed accelerates or decelerates the light. The light moves one pixel per millisecond by default. The rapid changes in cranking speed accelerate the light, while slowing down the cranking speed and by turning the handle in the opposite direction can decelerate the light. Considering the default animation and the interval time in the code, a speed value of less than 10 is designed to decelerate the light’s animation. Through this setup, we aim to examine how we experienced turning the small crank handle and no inertia to influence the speed of the moving light since this implementation was not executed in the **Dis-HANDLE** setup. Also, we will explore how the polarity of the speed affects the intuitiveness of the interaction as opposed to **Dis-GRINDER - SP - 0…59 - Wrap - Movement** where it excluded applying it.

3) Evaluation: Controllability, Repeatability, Understandability, Intuitiveness, and Engagement

Table 6 shows the overview of the evaluation of the experiments conducted in **Con-HANDLE**.

Title: Con-HANDLE							
Input form	Setup	Evaluation Criteria					
		Controllability	Repeatability	Understandability	Intuitiveness	Engagement
CD	0…255 - Wrap - Brightness	-	++	+	-	-
	0…255 - Wrap - Colour (Hue)	+/-	++	++	++	+
	0…59 - Wrap - Movement	+	++	++	++	+
SP	0…255 - Clip - Brightness	-	+/-	+/-	-	-
	0…180 - Clip - Colour (Hue)	- -	+/ -	-	+/ -	-
	0…59 - Wrap - Movement	+	++	++	++	++
						* - - (Bad), -, +/-, +, ++ (Good)

< Table 6. Overview: Evaluation (Con-HANDLE) >

Con-HANDLE - CD - 0…255 - Wrap - Brightness We could promptly change the cranking direction due to the absence of inertia of the crank handle. However, the handle's radius was smaller than our hand. It introduces struggles to precisely control the handle's position when one full handle turn corresponds to the entire value. It was easy to remember to update the value by changing the handle turn. As the handle's angular position indicated the value, it was easy to understand how to update the value in this setup. However, the implementation was not highly intuitive, particularly when observing an abrupt jump between the maximum and the minimum of the value. To address this, we chose to implement a gradual value transition between the maximum and the minimum value that can further complement the continuous cranking input. This will be shown in **Con-GRINDER - CD - 0…255 - Wrap - Brightness- (b) mirrored control (1 cycle).** The setup was not very engaging because the implementation reminded us of turning a knob, and a sudden value broke the flow. Since we were curious how tweaking the visual effect makes the experience more engaging, we expanded our approach, which will be shown in **Con-GRINDER - CD - 0…255 - Wrap - Brightness- (c) mirrored control (2 cycles).**

Con-HANDLE - CD - 0…255 - Wrap - Colour (Hue) It felt easy to change the cranking direction as there was no inertia in the handle. However, positioning the handle at an intended position felt difficult with the handle that has a small circumference. It was highly repeatable. The interaction simulated the one cycle of the colour transition with one full-handle turn that we are familiar with. The output aligned with what we expected from the hue's cyclic pattern. It was easy to predict the results from the cranking direction shift. The interaction achieved high understandability because the handle's angular position pointed at the hue value, clarifying how to position the handle to obtain an intended value. As the entire hue value range corresponded to one full-handle turn, it felt intuitive. The implementation was engaging since it simulated as if we were navigating the hue cycle by changing the cranking direction. However, it did not go beyond simulating one cycle of the hue transition, making us wonder about another way to improve engagement. We will introduce the extended approach in **Con-GRINDER - CD - 0…255 - Wrap - Colour (Hue) - (b).**

Con-HANDLE - CD - 0…59 - Wrap - Movement One can easily change the light's movement because the handle does not have inertia. Although the handle's circumference felt small to continue turning the handle, the value range (0-59) did not make it difficult to position the handle as intended compared to two other setups (0-255). Repeatability felt high due to the simplicity of the interaction. As the handle's angular position corresponded to the light pixel's position, it felt easy to understand the interaction, particularly where to position the handle to attain a certain value. By wrapping the value, a constant cranking in the same direction became possible with the light's movement moving along the loop LED structure. Together these made the interaction intuitive. It was engaging to have full control of the light system; the light stopped when the cranking stopped. However, since the implementation has been repeated multiple times, the following chapter will add more light pixels and examine how the visual effect influences the control, which we will implement in **Con-GRINDER - CD - 0…59 - Wrap - Movement- (b) 3 LED light pixels.**

Con-HANDLE - SP - 0…255 - Clip - Brightness It was difficult to maintain a consistent cranking speed due to the small, light handle that does not have inertia. The overall concept recalled a dynamo-based camping light, supporting the interaction to be repeatable. However, when observing the flickering lights at a fast cranking speed, it was unclear what the fast speed produced, making the interaction not very understandable. The interaction was still intuitive, reflecting the common association between fast-cranking links to higher values and slow-cranking links to low values. However, it was not engaging to observe the flickering lights at a fast speed, making the output look arbitrary. In the next chapter, we will update the crank input into the grinding wheel and how its inertia supports the control.

Con-HANDLE - SP - 0…180 - Clip - Colour (Hue) We struggled to keep the consistent cranking speed due to the small crank handle due to the absence of inertia, resulting in unintended colour displays at a fast cranking speed. Achieving a certain hue value from cranking over time was difficult to repeat. However, the concept was repeatable for the blue lights due to the common associations of the blue-coloured light to represent calmness. The red-coloured light was difficult to obtain because of the limitation in control with the small crank handle. The unclear implementation, particularly at a fast cranking speed, reduced the understandability of the interaction regarding how the input is being translated to the hue value. The translation between the colours and the cranking speed felt intuitive by leveraging the colour's meanings, particularly at the slow cranking speed. Yet, the fast cranking speed did not feel very intuitive as the light showed a wide range of hue values. There was no pronounced connection between the hue value and the cranking speed. When observing the unintentional flickering colour display, it felt like the input was not properly captured by the system. This further led to diminished engagement. The next chapter will use a grinding wheel and examine how it supports the colour control setup.

Con-HANDLE - SP - 0…59 - Wrap - Movement It could easily decelerate the light by making a sudden change in the cranking direction while it struggled to make a consistent cranking input, particularly at a fast speed to maintain its speed. Repeatability was high by leveraging the physical world; faster speed results in more energy and the directional speed was applied. The implementation was easy to understand how the cranking speed influences the speed of the light's movement by reflecting the physical world's behaviour. Applying the directional speed enhanced intuitiveness because turning the handle in an opposite direction fit the concept of decelerating the light's ongoing movement. This implementation was highly engaging because we could feel the tension between the light and us. With the cranking input, we could choose between supporting the light's movement or conflicting by cranking in the reversed direction. However, turning the small crank handle was not useful to continue cranking at a consistent speed in the same direction. It felt like we lost control of this interaction. From there, we thought about using a grinding wheel to maintain the speed input in the next experiment- **Con-GRINDER - SP - 0…59 - Wrap - Movement.**

4) Discussion & Conclusion

Con-HANDLE implemented the **CD** setup where one full handle rotation corresponds to the entire value range and the **SP** setup that maps the speed value (0-180) into the light's value.

Throughout these setups, **Con-HANDLE** showcased how the small crank handle influenced the control. In **Con-HANDLE-CD,** the absolute form of control facilitates understanding the influence of cranking as the handle's angular position corresponds to the value, and it further enables repeating the intended value when changing the cranking direction, as shown in **Con-HANDLE - CD - 0…255 - Wrap - Colour (Hue)** and **Con-HANDLE - CD - 0…59 - Wrap - Movement.** Although users can easily change the cranking direction due to the absence of inertia, the handle's circumference feels relatively smaller than our hands, making it difficult to precisely position the handle at an intended angle in one full handle turn. Wrapping the value fits the concept of the absolute form of control, and it allows implementation of the continuous value transition, as shown in **Con-HANDLE - CD - 0…255 - Wrap - Colour (Hue)** and **Con-HANDLE - CD - 0…59 - Wrap - Movement.** However, it can introduce a radical value jump between the maximum and the minimum value, making the interaction less intuitive, as shown in **Con-HANDLE - CD - 0…255 - Wrap - Brightness.** In the **Con-HANDLE-SP** setups, overall, it was difficult to understand what the speed results in due to the absence of inertia in the handle struggling to maintain the rotational speed, particularly at a fast cranking. Yet, the absence of inertia can facilitate changing the cranking direction or stopping it to implement acceleration or deceleration of the light, which makes the input feel controllable in **Con-HANDLE - SP - 0…59 - Wrap - Movement.** Now we compare the experiences to control each light attribute. For brightness control, both **CD** and **SP** setups had difficulties with the small size of the handle. The **CD** setup wrapped the value. The implementation with the small handle felt like turning a knob that allows continuous cranking, but the handle's radius was too small to position the handle, and the abrupt value transition between the maximum and the minimum value felt arbitrary. The **SP** setup simulated a dynamo-based camping light, while the difficulty in continuous cranking provided a flickering light, making the interaction less engaging. For colour control, **Con-HANDLE-CD** simulated an intuitive and understandable hue cycle by wrapping the value and one handle rotation corresponding to the entire value range. The use of the absolute handle position facilitated positioning the handle to achieve an intended value, although the handle's radius was too small and the sensor was too sensitive. In **Con-HANDLE-SP,** the difficulty in consistent speed control due to inertia resulted in a flickering colour display, making the control less intuitive; the reversed value mapping was useful as mentioned in the previous chapter. For the movement control, the small crank handle was not very beneficial for both **Con-HANDLE-CD** and **Con-HANDLE-SP.** In **Con-HANDLE-CD,** one can easily change the cranking direction. However, it was difficult to continue cranking in the wrapped value range and the handle's small radius made it difficult to position in one full-handle turn. In **Con-HANDLE-SP,** one can decelerate the light easily by making a sudden directional change because of the absence of inertia, but it makes it difficult to maintain cranking in the same direction.

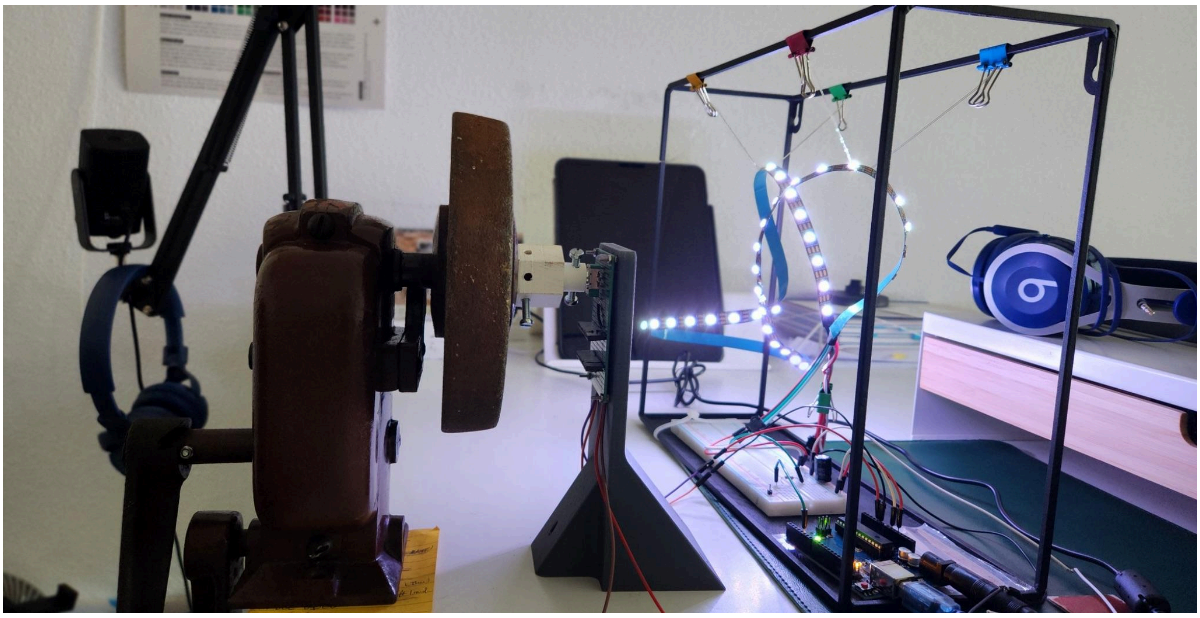
To sum up, **Con-HANDLE** illustrated that controlling the light with the small crank handle with a wrapped value range and the absolute form of control can support the light control leveraging on the 360-degree-based nature. However, the handle's small radius struggles to precisely position the handle at an intended angle and the absence of inertia in the handle makes it difficult to produce a consistent cranking speed. In the next chapter 4.2. Grinding Wheel, we will use the same grinding wheel from **Dis-GRINDER** and compare how turning the grinding wheel can influence obtaining an intended value to control the light.

4.2. Grinding Wheel (Con-GRINDER)

In the previous chapter **Con-HANDLE**, we used the continuous potentiometer to implement one full-handle rotation to correspond to the entire value range for each light attribute. **Con-HANDLE** illustrated that the absolute form of control made the interaction more understandable, although the cranking handle was too small to precisely control, and the absence of inertia made it difficult to produce a consistent cranking speed, which provided unclear outputs. Thus, this chapter 4.2. Grinding Wheel (this will be referred to as **Con-GRINDER**) will again use the grinding wheel introduced in **Dis-GRINDER** (Figure 12) which has a larger mass, a high inertia and a larger circumference of the handle's path to compensate for the aspects pointed out in **Con-HANDLE.** To execute comparable experiments, we will repeat the implementation that one full-handle turn corresponds to the entire value range. Along with the focus on obtaining an intended value from cranking, we will go further and explore simple forms of an interactive dialogue between the light and user, which has not been actively discussed in previous chapters, and our approaches will be explained in more detail in (2) Translation.

1) The form

The continuous sensor was mounted on the grinding wheel, where one full rotation of the crank handle makes nine rotations of the grinding wheel, a heavy stone that increases the mass and generates substantial rotational inertia (Figure 12).



< Figure 12. The crank (left) and the setup with the light (right) >

2) Translation

In **Con-GRINDER**, our approach covers obtaining an intended value from cranking as a direct form of control and exploring an interactive dialogue mediated by cranking. We implement the same behaviour as **Con-HANDLE** to compare the experiences with the grinding wheel as opposed to the small crank handle**.** For instance, **Con-GRINDER-CD** applies a scaling factor within the wrapped value to implement an absolute form of control so that the entire value range can be controlled by one full-handle turn, which will be explained on the following page. For **Con-GRINDER-SP,** we repeat the implementations in **Con-HANDLE-SP** but use the grinding wheel. Although the grinding wheel can achieve higher speed than the small crank handle due to its larger mass and bigger size, we kept the same speed range (0-180) to compare the controls with different crank handles. Additionally, **Con-GRINDER** will explore creating an interactive dialogue within the crank-based interaction context, given ideas from the domain of interactive art. This direction aims to examine the differences in the translation and how we experience cranking as an input as opposed to the context of the direct form of control. Reflecting on the structure of *audience-artwork interaction* suggested by Schraffenberger & van der Heide (2012), the interactive dialogue in our study context can be seen as an interaction that contains the user as an audience, the light system plays as an artwork or a performer and the crank as a communicative channel. Within this framework, the light should have its autonomous behaviour as part of the communication and the users can blend in its behaviour. When creating an interactive experience, controllability, understandability and high engagement from different levels of interactivity need to be considered (Bell, 1991; Sommerer & Mignonneau, 1999). In the previous chapters, we implemented these concepts in **Dis-GRINDER- SP - 0…59 - Wrap - Movement** and **Con-HANDLE- SP - 0…59 - Wrap - Movement,** and observed their potential to be further explored within different control setups. The experiments that will be carried out in this chapter are shown in Table 7, and those will be explained in more detail in the following pages.

Chapter Con-GRINDER			
Input form	**Setup (Range, Clip/Wrap, Light attribute)**	**Description**	**Details**
CD	0…255 - Wrap - Brightness	Bright (CW) - Dark (ACW)	(a) Scale factor 1/9
			(b) Mirrored control (1 cycle)
			(c) Mirrored control (2 cycles)
	0…255 - Wrap - Colour (Hue)	Increment (CW) - Decrement (ACW)	(a) Scale factor 1/9
			(b) Mirrored control (2 cycles)
	0…59 - Wrap - Movement	Increment (CW) - Decrement (ACW)	(a) 1 LED light pixel
		Increment & High brightness (CW) - Decrement & Low brightness (ACW)	(b) 3 LED light pixels
SP	0…255 - Clip - Brightness	Dark (slow) - Bright (fast)	(a) Obtain an intended value
		Default + Low brightness (slow) - Default + Higher brightness (fast)	(b) Influence the light's behaviour
	0…180 - Clip - Colour (Hue)	Blue (slow) - Red (fast)	-
	0…59 - Wrap - Movement	Decelerator (slow) - Accelerator (fast)	-
			*Clockwise (CW), Anti-clockwise (ACW)

< Table 7. Overview: Translation (Con-GRINDER) >

Con-GRINDER - CD

This implementation- a clockwise movement increases the value, while an anti-clockwise movement decreases it- remains the same considering its intuitiveness shown throughout the previous chapters. We will repeat the absolute form of control to compare the experiences between types of handles as opposed to **Con-HANDLE.** The setups that avoid wrapping the value and the sensor scaling will be excluded to prevent repetitiveness in the study based on the remarks from **Dis-GRINDER-CD;** the setups without applying the scale factor result in abrupt value transitions and it is difficult to make an interactive experience. To implement the sensor scaling, we will accumulate the rotational angle, ranging from 0° (no rotation) to 3239° (rotation from nine times). Its cumulative rotational angle is divided by nine, indicating the gear ratio. The calculated value is mapped into the value for each light attribute. In addition, we will explore the light display that can achieve higher engagement in **Con-GRINDER - CD** because this aspect has not been actively explored in the previous chapters. For this, we will implement more value transitions with one full handle turn, which is less common in other crank-based interactions but can be interesting to examine our experience in this study context. We excluded creating an interactive dialogue in **Con-GRINDER - CD** due to the limitation in implementing an interaction controlled by changing cranking directions. Below are our approaches for each light attribute.

Con-GRINDER - CD - 0…255 - Wrap - Brightness controls the intensity of the brightness level by changing the cranking direction in three conditions - **(a)** scale factor 1/9, **(b)** Mirrored control (1 cycle), and **(c)** Mirrored control (2 cycles).

(a) Scale factor of 1/9: By applying a scale factor of 1/9, we can simulate the behaviour of one cycle of the brightness transition in one full-handle turn. Meaning that we have to make multiple rotations (a total of 3239 degrees) to reach the maximum value of the attribute. **Con-HANDLE - CD - 0…255 - Wrap - Brightness** already showed that the implementation without clipping can cause an abrupt value transition between the maximum and the minimum brightness**.** Yet, through this setup, we will make a comparable experiment examining how the experience differs with the larger handle radius.

(b) Mirrored control (1 cycle): To simulate a smooth transition between the extremes while turning the handle, the value range of the full handle turn is divided by half. In other words, the first half cycle increases the value, while the second half cycle decreases the value. Through this setup, we aim to examine how we experience this setup when turning the handle with high inertia and how it resolves the remarks from **Con-GRINDER - CD - 0…255 - Wrap - Brightness- (a) Scale factor of 1/9.**

(c) Mirrored control (2 cycles): To explore creating an interactive dialogue, we expand **Con-GRINDER - CD - 0…255 - Wrap - Brightness- (b) Mirrored control (1 cycle)** by simulating a behaviour where one full handle turn implements two full cycles of increasing and decreasing brightness. Through this approach, we will examine how we experience this simulation as it is less conventional to experience one full-handle turn and whether this approach leads to an engaging experience.

Con-GRINDER - CD - 0…255 - Wrap - Colour (Hue) updates the hue value (0-255) by changing the cranking direction in two conditions - **(a)** scale factor 1/9 and **(b)** 2 hue cycles.

(a) Scale factor 1/9: We can simulate one cycle of the hue transition in one full-handle turn through the use of a scale factor 1/9. This requires multiple rotations of the sensor (a total of 3239 degrees) from one crank handle rotation to the maximum range of the hue. The previous **CD** setups showed high intuitiveness in the one cycle of the hue transition. Concerning this, the remark in this setup will be used to compare our experience when turning as opposed to **Dis-GRINDER - CD - 0…255 - Wrap - Colour (hue)** and **Con-HANDLE - CD - 0…255 - Wrap - Colour (Hue)**.

(b) 2 hue cycles: It simulates two complete hue transitions with one crank handle rotation considering its novelty compared to the common single-cycle of the hue transition. It aims to examine how turning the handle with high inertia can achieve an intended value within this multiple-hue transition in one cycle, and how the experience differs compared to **Con-GRINDER - CD - 0…255 - Wrap - Colour (Hue) - (a) Scale factor 1/9** and its potential to enhance engagement of the experience.

Con-GRINDER - CD - 0…59 - Wrap - Movement updates the position of the LED pixel through the cranking direction in two conditions - **(a)** 1 LED light pixel and **(b)** 3 LED light pixels.

(a) 1 LED light pixel: With the use of a scale factor, it simulates one cycle of the transition in the light's position in one full-handle turn. Multiple rotations of the sensor (a total of 3239 degrees) are required to reach the maximum position value of the light. We will compare the experience in this setup and **Dis-GRINDER - CD - 0…59 - Wrap - Movement** and **Con-HANDLE - CD - 0…59 - Wrap - Movement** regarding how we experience the use of the absolute handle's angular position and turning the handle with a larger mass and its high inertia.

(b) 3 LED light pixels: With the same logic as the **(a)** setup, the cranking direction moves three activated lights that are evenly spaced along the LED strip from the shift in the cranking direction. Considering the size of the LED strip, three lights can be sufficient to amplify the visual impact. Our aim is to examine how the revised visual effect leads to improving its engagement.

Con-GRINDER - SP
The speed value (0-180) will be mapped into the value for each light attribute to examine the experience of how turning the grinding wheel's handle influences obtaining an intended value. The direction of the speed is applied to the movement control, while the brightness control and the colour control exclude it to enhance the intuitiveness of the interaction, as showcased in **Con-HANDLE.** To create an interactive dialogue, the setups will simulate the autonomy of the system so that the interaction does not fully rely on the user's input while it can still be controllable to trigger different effects. In other words, we will implement animation in the light to represent its autonomy in the brightness control and the movement control, and the speed input (0-180) will influence the animation. We exclude implementing an interactive dialogue for colour control due to the illustrated difficulties in controllability and understandability, which can influence the whole experience accordingly. The following will illustrate the details of each setup.

Con-GRINDER - SP - 0…255 - Clip - Brightness controls the intensity of the brightness level with the cranking speed in two setups, and each title indicates its aim- **(a)** Obtain an intended value and **(b)** Influence the light's behaviour.

(a) Obtain an intended value: It maps the speed input (0-180) to a brightness level (0-255). Although the main logic in this setup remains the same as the previous experiments, we will pay more attention to how the experience differs with the different cranking setups.

(b) Influence the light's behaviour: We simulated a behaviour where the speed (0-180) is added to the brightness value of an ongoing animation which updates the brightness level by 1 during 100 milliseconds of the interval time as if the light is breathing to represent autonomy of the system. While the previous setup **(a) Obtain an intended value** relies on the user's input since the light dims when there's no input, this setup is built upon additive progression, representing the cranking speed amplifies or supports the brightness. Through this, we are interested in how understandable this interaction can be and how we experience controlling the input through the grinding wheel.

Con-GRINDER - SP - 0…180 - Clip - Colour (hue) maps the speed range (0-180) to the hue value (0-180). It aims to examine controllability with the revised crank setup compared to **Dis-GRINDER - SP - 0…180 - Clip - Colour (hue)** and **Con-HANDLE - SP - 0…180 - Clip - Colour (hue).**

Con-GRINDER - SP - 0…59 - Wrap - Movement simulates a behaviour where the cranking speed and its direction accelerate or decelerate the light's movement without offset. To implement the light's movement, indicating its autonomy, the pixel's position is updated every 10 milliseconds. Acceleration can be achieved by a fast cranking speed higher than 10. The deceleration can be achieved in two ways- slowing down the cranking speed to less than 10 and turning the handle in the opposite direction.

3) Evaluation: Controllability, Repeatability, Understandability, Intuitiveness, and Engagement

We applied the same evaluation criteria to both the setups focusing on direct control and the setups aiming to create an interactive dialogue, considering their relevance to this study context. The conditions focusing on interactive dialogue include more evaluation of the engagement aspect. Table 8 illustrates an overview of the evaluation of the experiments in **Con-GRINDER**.

Title: Con-GRINDER							
Input form	**Setup**	**Details**	**Evaluation Criteria**				
			Controllability	**Repeatability**	**Understandability**	**Intuitiveness**	**Engagement**
CD	0…255 - Wrap - Brightness	(a) Default (scale factor applied - 9)	+	++	+	+	+
		(b) Mirrored control (1 cycle)	+/-	+	++	++	++
		(c) Mirrored control (2 cycles)	- -	+	- -	- -	- -
	0…255- Wrap - Colour (Hue)	(a) Default (scale factor applied - 9)	+	++	++	++	+
		(b) Mirrored control (2 cycles)	- -	-	- -	- -	-
	0…59 - Wrap - Movement	(a) Default (scale factor applied - 9)	+	++	++	++	+
		(b) More light pixels	+	++	+	++	++
SP	0…255 - Clip - Brightness	(a) Default	+	++	++	++	+
		(b) Brightness amplifier	-	-	+/-	+/ -	+
	0…180 - Clip - Colour (Hue)	-	+	+	+	+	+
	0…59 - Wrap - Movement	-	+	++	++	++	++
* - - (Bad), -, +/-, +, ++ (Good)							

< Table 8. Overview: Evaluation (Con-GRINDER) >

Con-GRINDER - CD - 0…255 - Wrap - Brightness We implemented the brightness control in the absolute form of control across three setups- **(a)** scale factor 1/9, **(b)** mirrored control (1 cycle), and **(c)** mirrored control (2 cycles).

(a) Scale factor 1/9: Given the handle's large circumference of the handle, it felt less sensitive to position the handle with one full-handle turn compared to **Con-HANDLE - CD - 0…255 - Wrap - Brightness**. However, the grinding wheel's high inertia struggled to make quick changes in the cranking direction and stop the handle. With the simple interaction that updated the value by rotating the handle either clockwise or anticlockwise, the implementation was easy to repeat. The immediate system response allowed us to easily grasp how the interaction works. The handle's position informed the value, informing what the current value is. There was an abrupt transition between the maximum and minimum values, which felt unexpected and not very intuitive. This abrupt value jump reduced the engagement of the interaction, particularly from the visual effect perspective.

(b) Mirrored control (1 cycle): The implementation avoided a sudden value jump mentioned in the **(a)** setup. In this setup, one struggled to change the cranking direction and precisely position the handle due to the wheel's high inertia. As half of the cycle reached the entire value range, more precision in positioning the handle was needed. The implementation was easy to recall with a single handle turn that clearly shows the increment and the decrement. It resulted in a high understandability by using the absolute form of control, which defined how the value is increased and decreased in one full-handle turn. Intuitiveness was high because the value transition in the wrapped value range aligned well with the continuous cranking. Engagement was high because it simulated a persistent brightness change that prompted us to continue cranking.

(c) Mirrored control (2 cycles): It felt difficult to precisely position as one handle turn simulated two cycles of value transitions, which felt particularly difficult by turning the handle with high inertia and a larger circumference. It was not very easy to repeat the implementation due to the multiple cycles of increment and decrement. Observing too many transitions in one cycle made it difficult to grasp how cranking influenced value. It resulted in low intuitiveness because one handle turn changed the value too fast, which made the setup not in full control. The light display seemed arbitrary with so many value transitions, particularly when turning the handle at a fast speed; it was hard to be fully engaged with.

Con-GRINDER - CD - 0…255 - Wrap - Colour (Hue) It controls the hue value with the absolute form of control in **(a)** scale factor 1/9 and **(b)** 2 hue cycles.

(a) Scale factor 1/9: When turning the handle, a spectrum of hue was shown. When attempting to obtain an intended hue value, the wheel's high inertia made it difficult to suddenly stop the handle or change the cranking direction. The implementation was highly repeatable with our familiarity with the cyclic pattern of the hue value. This further allowed us to easily understand the implementation. The output was predictable and aligned with what we expected from the hue spectrum. As the handle's absolute angular position corresponds to the hue value, we could position the handle to obtain an intended value. By wrapping the value and using the absolute form of control, the cranking input movement aligned well with the hue's cyclic pattern, making the whole experience intuitive. It was an engaging implementation as the light provided a colour transition aligned to the continuous rotational input.

(b) 2 hue cycles: To expand our approach, we came across the **(b)** setup which implements two cycles of the value transition with one full handle turn. Given the handle's large circumference and the grinding wheel's high inertia, it was difficult to position the handle in the cycle. This setup allowed continuous cranking as the value updated without any value jump; continuous cranking to update the value was repeatable. However, the concept was not very easy to recall. Considering this mismatch in our expectation of one cycle of value transition, observing dynamic colour transitions in one full-handle turn felt less intuitive. It was not very engaging because it felt that the light was not under control.

Con-GRINDER - CD - 0…59 - Wrap - Movement The cranking direction is applied to the direction of the light's movement, and our implementations are **(a)** controlling a single light pixel and **(b)** controlling three light pixels.

(a) 1 LED light pixel: The value range felt small when turning a handle with a huge circumference. Also, the high inertia made it difficult to change the cranking direction or stop the crank handle to position the light in a targeted position. The interaction was easy to repeat as the cranking direction was directly reflected in the lights' movement. By using the scale factor, we could easily observe the impact of the input. Also, we could know where the current value is based on the handle's angular position. The interaction felt intuitive because the light changed its position along the strip at a not-too-fast nor too-slow speed when turning the handle with a bigger size and mass. However, as this experience has been implemented multiple times with different setups, we were wondering how the adjustment in the visual effect would differentiate the experience.

(b) 3 LED light pixels: As there was no modification involved besides the numbers of the light pixels, controllability and repeatability felt similar to the **(a)** setup. It struggled to precisely position the light by changing the cranking direction or stopping the rotation due to the high inertia. The overall concept felt easy to repeat due to the simplicity of the interaction. It was easy to observe how the cranking direction influences the light's movement. Yet, it was unclear to grasp which specific light was under control since the three lights were moving simultaneously. It felt intuitive because the cranking direction and the direction of the light's movement matched. It was engaging to observe its captivating light display that resembled blooming or wing flapping when rotating the handle.

Con-GRINDER - SP - 0…255 - Clip - Brightness The cranking speed increases or decreases the intensity of the brightness, and we implemented it in **(a)** focusing on obtaining a specific value and **(b)** amplifying brightness through cranking speed.

(a) Obtain an intended value: With the high inertia of the grinding wheel, maintaining a consistent speed was easy, supported by the wheel's momentum, but it introduced difficulties in making quick changes in the cranking speed. Familiarity with a dynamo-based camping light example facilitated repeating the overall interaction, which was also easy to understand. The interaction felt intuitive by leveraging the common connection between the fast speed resulting in a pronounced effect and the slow speed for a small effect. It was engaging to experience the simulation of the dynamo-based light with another crank interface.

(b) Influence the light's behaviour: By default, the light has an ongoing animation that changes the brightness level by 1 every 100 milliseconds. The cranking speed is added to the brightness level. The wheel's high inertia facilitated making a constant cranking input, but it was difficult to promptly change the speed. It was easy to repeat the interaction because the implementation reminded me of an interaction where cranking is used as a power source. In this additive progression, it was easy to understand that the fast cranking speed amplified the intensity of the brightness. However, the impact of the slow cranking speed was difficult to observe and thereby less understandable. It felt intuitive when turning the handle with the fast cranking speed. It reminded us of adding more power to the light. However, the slow speed did not result in a perceivable influence on the light's behaviour, and the setup did not apply the directional speed. These made the experience less intuitive. It was engaging to observe how the fast cranking speed amplified the brightness of the light, although the flickering lights from the slow speed contradicted the intended calm atmosphere of the default animation.

Con-GRINDER - SP - 0…180 - Clip - Colour (Hue) The cranking speed (fast-slow) is translated into the light's hue. It felt easy to make a consistent cranking speed while changing the speed promptly was challenging due to the wheel's high inertia. The interaction was repeatable based on our familiarity with the common association of the meanings of the colour. With the grinding wheel that facilitated controlling the cranking speed, it was clear to observe how the speed was translated and thereby the interaction became more understandable. The implementation felt intuitive due to the use of the reversed value range that maps the low speed to the higher hue value whereas the fast speed to the lower hue value. This aligns with our common experience that we tend to perceive the impression of the colours. In line with this, it was engaging to experience because the cranking input creates and represents the meaning of the colours.

Con-GRINDER - SP - 0…59 - Wrap - Movement We implemented the acceleration and deceleration of the moving light through the cranking speed. Acceleration was easily executed with the grinding wheel's handle which can achieve a faster cranking speed than the threshold of 10. However, the wheel's large inertia contained resistance from the wheel's momentum, making it difficult to reverse the cranking direction and achieve a speed, which is less than the threshold. The challenges in making different cranking speeds promptly led to difficulties in repeating an intended value. However, the overall concept of the interaction felt easy to repeat by leveraging on the intuitiveness of the experience. As the setup represented the physical world's interaction and provided a prompt response from the cranking, it felt easy to understand. Applying the directional speed to the light's movement represented real-world physics, which enhanced the intuitiveness of the interaction. This implementation was very engaging because the grinding wheel's high inertia supported us to continue cranking at a consistent speed. It also simulated a tension that the system is not allowing the user to take full control of. Additionally, when cranking in the same direction that matched the light's movement, it felt like we chose to support the light. To decelerate the light, we crank in the reversed direction, and a small tension between the light and us could be felt. Once we reverse the cranking direction, the wheel's high inertia facilitated the input movement.

4) Discussion & Conclusion

This chapter **Con-GRINDER** illustrated how the grinding wheel influenced the direct forms of controls and a control for an interactive experience. In **Con-GRINDER-CD**, all the setups struggle to promptly change the cranking direction or stop cranking due to the wheel's inertia. Also, it felt more difficult to precisely position the handle where one full-handle rotation corresponds to the entire value range. Regardless of the difficulty with positioning the handle due to the wheel's inertia, the absolute position of the handle indicates the light's value in 360-degree coordinates, giving us a cue where to position the handle to obtain an intended value, and it made interaction more understandable. To make the control more engaging, we expanded our approaches by implementing more value transitions that can be achieved by one handle rotation in **Con-GRINDER - CD - 0…255 - Wrap - Brightness- (c)** and **Con-GRINDER - CD - 0…255 - Wrap - Colour (Hue)- (b).** However, both illustrate that multiple value transitions in one full handle turn contradict our expectation that it often corresponds to one cycle of value transition. Also, with the grinder wheel's inertia, it is difficult to precisely control a full value range that can be achieved by a much smaller handle turn. Together these show that the absolute form of control within the wrapped value range can provide an intuitive experience, but it is difficult to precisely control the handle due to the wheel's high inertia. In **Con-GRINDER-SP**, all the implementations illustrated that the grinding wheel's high inertia facilitates maintaining the cranking speed, which ensures a clear translation, whereas its high inertia hinders us from making a prompt change in speed. This control felt more beneficial to the setup that influences the light's behaviour where it needs continuous input while the difficulty in control becomes part of the experience. The following will compare the input forms controlling each light attribute. For brightness control, the **CD** setup, which wrapped the value, struggled to position the handle precisely due to inertia. It was particularly difficult when half or a smaller handle turn can correspond to the entire value range- **Con-GRINDER - CD - 0…255 - Wrap - Brightness - (b) mirrored control (1 cycle)** and **Con-GRINDER - CD - 0…255 - Wrap - Brightness- (c) mirrored control (2 cycles)**. However, we observed that the mirrored control was engaging and intuitive as it addressed the abrupt value jump between the maximum and the minimum value while cranking. The mirrored control with 2 cycles of value translation in one handle turn felt less intuitive, rather arbitrary. In the **SP** setup, one felt easy to interact with the high inertia, facilitating consistent cranking. For the colour control, the **CD** setup simulated one cycle of the hue's cyclic pattern, which was intuitive and easy to understand. However, the wheel's high inertia struggled to position the handle as intended, particularly when one handle turn corresponded to the entire value range. By contrast, the **SP** setup benefited from the wheel's inertia, which led to providing an output that was captivating to interact with. In the movement control, the **CD** setup resulted in difficulties in positioning the light as intended due to the high inertia, especially one handle turn that corresponded to the entire value. Yet, the inertia and the wrapped value enabled cranking in the same direction, making the input more ongoing. By contrast, the **SP** setup provided an experience that was controllable and engaging. The high inertia facilitated maintaining a consistent cranking speed and even acceleration, although it made it difficult to decelerate. Reflecting on these findings, we conclude that the grinding wheel's high inertia can be more beneficial in the **SP** setup to maintain the cranking speed than the **CD** setup to make a sudden change while the entire value can be achieved by one full-handle rotation.

Now we compare the implementations for the interactive dialogue that we introduced in the **SP** setup, particularly in the brightness control **Con-GRINDER - SP - 0…255 - Clip - Brightness - (b) Influence the light's behaviour** and the movement control **Con-GRINDER - SP - 0…59 - Wrap - Movement.** Using the grinding wheel was beneficial for both setups because its inertia supported us to continue cranking at a consistent speed. However, we observed that the movement control aligns well with the aim of this study compared to the brightness control. For the brightness control, the autonomy of the system was shown through ongoing animations that change the brightness level every 100 milliseconds, and the speed was added on top of the ongoing light animation. As this implementation applied the additive progression to the light's animation, it was difficult to observe how cranking speed influenced brightness levels, particularly at slow speeds, which resulted in no noticeable change. Although it represented the light's autonomy, our influence was not captured and thereby this setup could not successfully implement an interactive dialogue. On the other hand, in the movement control, the light changes its position every 10 milliseconds, and the crank speed accelerates or decelerates the light's movement. During the interaction, it was clear to observe the autonomy of the system and ours, and it was easy to observe the influence of the cranking due to the wheel's high inertia supporting the speed control. The high inertia can also make the speed control difficult, especially when stopping the handle or making a directional change. However, it felt like the system was challenging our input, highlighting the tension between the light and the user. Reflecting on these, we conclude **Con-GRINDER - SP - 0…59 - Wrap - Movement** as our implementation for the interactive dialogue.

With that, we have compared the crank-based interactions controlled by the grinding wheel as the direct form of control and an input for an interactive dialogue through numerous setups. In the next chapter, we will compare **Con-HANDLE** and **Con-GRINDER** in terms of how different types of cranks influence the experience.

4.3. Continuous Sensor: Discussion & Conclusion

In chapter 4. Continuous Sensor: Experiments, we used the 360-degree continuous potentiometer mounted to the small crank handle (**Con-HANDLE)** or the grinding wheel (**Con-GRINDER)**. These simulated a behaviour where one full handle rotation reached the entire value range. Below cross-evaluates the setups of the continuous sensor concerning the cranking direction (**CD**) and the cranking speed (**SP**) controlled by the cranking handle (**HANDLE**) or the grinding wheel (**GRINDER**) in four sections, (1) **Con-HANDLE-CD & Con-HANDLE-SP,** (2) **Con-GRINDER-CD & Con-GRINDER-SP,** (3) **Con-HANDLE-CD & Con-GRINDER-CD,** and (4) **Con-HANDLE-CD & Con-GRINDER-CD.** The setups without any common configuration are excluded, such as **Con-HANDLE-CD & Con-GRINDER-SP** and **Con-GRINDER-CD & Con-HANDLE-SP.** Also, we exclude comparison on exploring an interactive dialogue since the experiments in **Con-HANDLE** were limited to creating a direct form of control. This will be discussed in the next chapter 5. Conclusion.

1) Con-HANDLE-CD & Con-HANDLE-SP

Now we compare the small crank handle setups controlled by **CD** or **SP**. Both **Con-HANDLE-CD** and **Con-HANDLE-SP** pointed out the influence of the small size of the handle and the absence of inertia. In **Con-HANDLE-CD**, one can easily position the handle as intended to achieve a certain value due to the absence of inertia, but its small radius requires more precision in positioning the handle with one full handle turn. By contrast, in **Con-HANDLE-SP,** the small handle size and the absence of inertia make it difficult to maintain a consistent cranking speed. These findings show that the small crank handle struggles to obtain an intended value, while the absence of inertia can be useful in the **CD** setup when promptly changing the handle's position.

2) Con-GRINDER-CD & Con-GRINDER-SP

The following compares how the grinding wheel that has significant inertia influences the **CD** setup and the **SP** setup. The wheel's high inertia enables providing a constant input, highlighting its benefit in the speed-based control towards a more understandable interaction, as shown in **Con-GRINDER - SP - 0…255 - Clip - Brightness - (a) Obtain an intended value.** However, it can also introduce difficulty in stopping the handle or changing the cranking direction in **Con-GRINDER-CD** and **Con-GRINDER - SP - 0…59 - Wrap - Movement.** In other words, the wheel's inertia facilitates cranking constantly, especially when the value is wrapped in the **CD** setup, and it also makes the **SP** setups more controllable. Yet, it can make it difficult to make a prompt change in its position or its speed.

3) Con-HANDLE-CD & Con-GRINDER-CD

We now compare the **CD** setup controlled by a small crank handle or a grinding wheel. In both **Con-HANDLE-CD** and **Con-GRINDER-CD,** the absolute handle position corresponds to the value, and the impact of the input becomes more understandable and repeatable. However, each setup resulted in different experiences with one full handle rotation that corresponds to a wide range of values. For **Con-HANDLE-CD,** one can promptly stop the handle as there's no inertia, but the handle's small radius is relatively smaller than our hand so the small angular change already updates the value at a big scale. On the other hand, the grinding wheel setup is less sensitive to obtain an intended value due to its larger circumference allowing us to turn the handle with a bigger movement. However, the high inertia makes it difficult to stop the handle as intended.

4) Con-HANDLE-SP & Con-GRINDER-SP

The following discusses the comparison of the **SP** setups controlled by a small crank handle or a grinding wheel to see how the inertia influenced the interaction. The absence of inertia in the small crank handle struggles to maintain consistent rotational movement, making the output hard to understand, although it is effective in implementing a sudden directional change, as mentioned in **Con-HANDLE - SP - 0…59 - Wrap - Movement.** On the other hand, the grinding wheel's high inertia in **Con-GRINDER-SP** enables to produce consistent cranking speed and further leads to a more understandable interaction, while it struggles to promptly simulate acceleration or deceleration of the light from cranking in **Con-HANDLE - SP - 0…59 - Wrap - Movement.** These findings highlighted the wheel's high inertia can be useful in speed-based control to make a consistent speed input compared to the small crank handle.

Up to this point, we compared the experiments in Chapter 4. Continuous Sensor: Experiments with the main focus on cranking as the direct form of control to achieve an intended value. Thus, in the next Chapter 5. Conclusion, we will discuss the setups using different sensors and the experience that mainly focuses on creating an interactive dialogue, followed by suggestions for further studies.

5. Conclusion

Throughout the study, we explored numerous crank-based interactions and attempted to go beyond the utilitarian perspectives in interaction design under the question - ***What forms of crank-based interaction can we imagine in the context of embodied light control?*** To answer this question, we conducted iterative prototyping using two different types of cranks (the small crank handle and a grinding wheel) and two different sensors. Starting from cross-evaluating the experiences, we will discuss the interactive dialogue and conclude this study by pointing out its limitations and the potential for further studies.

Cross-evaluation

Based on the controlled light attributes and the types of input forms throughout **Dis-HANDLE, Dis-GRINDER, Con-HANDLE** and **Con-GRINDER**, we will cross evaluate the setups in six categories- (1) Brightness control-CD, (2) Brightness control-SP, (3) Colour control-CD, (4) Colour control-SP, (5) Movement control-CD, and (6) Movement control- SP.

1) Brightness control-CD

By changing the cranking direction, one can increase and decrease the intensity of the brightness level. When the value is clipped in the multiple-turn-based control, the small crank handle (**Dis-HANDLE)** can obtain the intended value, despite its small radius. As it has no inertia, one can easily change the cranking direction to promptly see the value update when encountering the value limit. However, the small crank's absence of inertia makes it difficult to maintain cranking. The grinding wheel (**Dis-GRINDER),** by contrast, can be useful for making constant cranking with its high inertia. Yet, it can introduce difficulties in making a sudden stop or direction change, which is not useful when the value is clipped. Considering we are prone to keep cranking once we start cranking, clipping the value can be less intuitive to interact with as it hinders us from making continuous input movement. The clipping-based implementations are close to turning a knob to turn on-off the light. When one full handle turn corresponds to the entire value range, the handle's angular position informs us of the value, making the interaction more understandable and repeatable. Yet, both **Con-HANDLE** and **Con-GRINDER** have difficulties in control. **Con-HANDLE** has a small circumference, which is sensitive to updating the value, while the grinding wheel's high inertia struggles to position the handle as intended. As shown in **Con-HANDLE - CD - 0…255 - Wrap - Brightness** and **Con-GRINDER - CD - 0…255 - Wrap - Brightness- (a) scale factor 1/9,** simply wrapping the value can cause an abrupt value jump between the maximum and the minimum intensity of the brightness. To address this, we implemented a mirrored control in the **Con -GRINDER** setup. The handle's enlarged circumference facilitates positioning the handle at an intended angle. However, the wheel's inertia is still not beneficial for positioning the handle in this context, since the entire value range can be reached by the half range of the handle turn; more precision is needed.

2) Brightness control-SP

The following compares **Dis-HANDLE, Dis-GRINDER, Con-HANDLE** and **Con-GRINDER** where the cranking speed (fast-slow) was translated to the intensity of the brightness value. Overall, the interaction feels understandable and intuitive because the simulated behaviours remind us of a dynamo-based camping light. The experiments showed no significant difference between the sensors. However, the findings show that the handle types can influence the experience. When turning the small crank handle in **Dis-HANDLE** and **Con-HANDLE,** maintaining a consistent cranking speed is difficult due to its small radius, small mass and the absence of inertia. With its difficulties in controlling the cranking speed, the system resulted in flickering light effects, which turn on-off arbitrarily. By contrast, the grinding wheel in **Dis-GRINDER** and **Con-GRINDER** has larger circumferences, mass and high inertia, enabling an understandable output- increasing or decreasing brightness depending on the cranking speed. These show that the simulated cranking speed-based brightness control feels intuitive to interact with, and the grinding wheel is more beneficial in obtaining a value with the cranking speed. Furthermore, it resulted in an interaction where the cranking becomes the power source of the interaction.

3) Colour control-CD

Now we compare the setups that control the hue value by changing cranking directions. As shown in the **Dis-HANDLE** setup, clipping the value can inform the starting point or the endpoint of the colour spectrum, particularly when the handle's angular position does not correspond to the hue value. When encountering the value limit, the small crank handle is effective in promptly changing the cranking direction. However, turning the handle within the clipped value does not feel aligned with the continuous rotational movement of the input and the hue's cyclic pattern that we are familiar with. As shown in the **Dis-GRINDER** setup, wrapping the value allows continuous cranking in the same direction, and this aligns well with the cyclic pattern of the hue value. However, the handle's relative position does not inform how many turns to obtain an intended value, making the experience less intuitive. When one full handle turn reaches the entire hue value range in **Con-HANDLE** and **Con-GRINDER**, it feels intuitive and easy to repeat, because it aligns with the one cyclic pattern of the hue. Precise control is difficult because the handle has a small circumference in **Con-HANDLE** and the wheel's high inertia struggles to position the handle in **Con-GRINDER**. These findings show that wrapping the value supports simulating a cyclic hue pattern, As it aligns with the continuous rotational cranking movement, the interaction can be more ongoing and thereby more engaging. Also, ine handle turn covering the entire value fits well with our common understanding of the hue cycle. Despite the difficulty in positioning, the absolute handle position can effectively inform the corresponding hue value, facilitating obtaining a value.

4) Colour control-SP

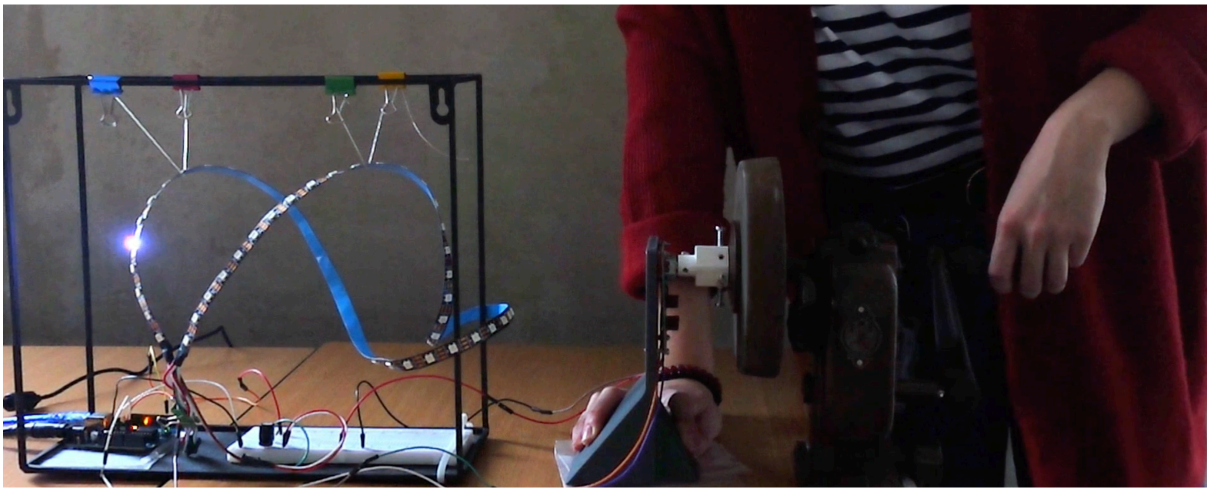
The following compares the experiences where the cranking speed (fast-slow) was translated to the hue value. Although there was no big difference experienced between using different sensors, one can feel that the **GRINDER** setups are more relevant to controlling the colour than the **HANDLE** setups. The wheel's high inertia, its larger handle size and mass support cranking continuously and thereby effectively control the speed to obtain an intended value. Across the whole setup, the fast cranking speed is mapped to the highest hue value (0 to red) and the slow cranking speed is mapped to the highest hue value (180 or blue). This design choice is beneficial to understanding the influence of the input because it aligns the common associations of the colours with their meanings. These show that cranking can be used as a speed-based colour control, and an intuitive interaction can be created by using a grinding wheel and the hue range that matches the colour association (blue for slow, red for fast).

5) Movement control-CD

This section compares the setups where the cranking direction determines to which direction the light is changing its position. When the value is clipped, the small crank handle in **Dis-HANDLE** feels beneficial to changing the cranking direction due to the absence of inertia, but the clipped value does not match the looped LED structure and the cranking's continuous movement. In **Dis-GRINDER, Con-HANDLE,** and **Con-GRINDER,** the value is wrapped. This simulated a more intuitive interaction by allowing us to continuously turn the handle in one direction and the light's movement follows along the LED strip; the movement of the input and the output aligned. Among them, the **Dis-GRINDER** setup simulated that the full value range is obtained by multiple turns and the handle's angular position does not correspond to the position value. This setup showed that the scaling factor can be modified depending on the intention of the experience. As **Dis-GRINDER - CD - 0…59 - Wrap - Movement** shows, the scale factor 1/9 corresponding to the gear ratio 1:9 provided a physically demanding experience compared to the visual effect. Additionally, the relative handle position makes it difficult to know how many turns to make to position the light pixel on the LED strip. When one full handle turn reaches the entire value range in **Con-HANDLE** and **Con-GRINDER,** the handle's output becomes understandable when the handle's angular position corresponds to the position value. However, the small crank handle's circumference is small, leading to difficulty in precise position. The handle has no inertia, which further struggles to constantly turn the handle. By contrast, the grinding wheel's high inertia has difficulty in promptly stopping the handle or positioning the light pixel as intended. To conclude, the small crank handle can be useful when a quick direction change is needed, while the grinding wheel can be more useful when a continuous rotational input is needed. In this movement control context, wrapping the value fits the looped light structure, enhancing engagement and intuitiveness of the experience.

6) Movement control- SP

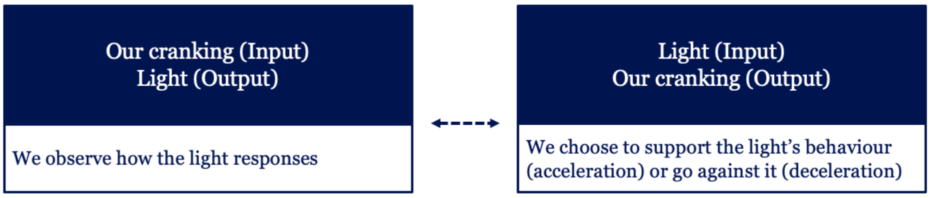
In **Dis-GRINDER, Con-HANDLE,** and **Con-GRINDER**, we simulate the single light pixel changing its position every 10 milliseconds, and the fast cranking speed accelerates it, while the slow speed decelerates it. There was no big difference between the discrete sensor and the continuous sensor, one can feel the difference between the small crank handle and the grinding wheel. The small crank handle used in **Con-HANDLE** can promptly change the crank direction to decelerate due to the absence of inertia, but it feels difficult to keep a consistent cranking speed. By contrast, the grinding wheel's inertia shown in **Dis-GRINDER** and **Con-GRINDER** allows for cranking consistently while introducing difficulties in making a sudden directional change. When comparing **Dis-GRINDER** and **Con-GRINDER,** we observed that applying directional speed in the input can make the experience more intuitive because it reflects the physical world. From there, we conclude that the grinding wheel can be more useful to continue cranking, although it still feels difficult to make a sudden direction change while cranking, which can enhance the engagement aspect that will be further described in the following section.



< Figure 13. Experiment: Con-GRINDER-SP- 0…59 - Wrap - Movement >

Interactive Dialogue

Given the ideas from audience-artwork interaction, we implemented an interactive dialogue to discover more potential of the crank interaction that the direct form of control did not touch upon. We began by simulating the light's autonomy so that there are two-way dynamics in the experience. Either the cranking input or the light (the system) can be the input. Among the created setups, we found the most potential in **Con-GRINDER-SP- 0…59 - Wrap - Movement**, simulating that the cranking speed accelerates or decelerates the light's movement (Figure 13). Its interaction unfolds in the following manner (Figure 14). One turns the handle at varying speeds and observes how the cranking input influences the light's movement; the cranking is an input while the light is an output. From observing the light, one chooses to support the light's behaviour through acceleration cranking or go against it through deceleration; the light becomes the input, while our input becomes the output.



< Figure 14. Interaction Flow Diagram >

When turning the grinding wheel, the wheel's high inertia makes it difficult to stop the handle or promptly change the direction. In this interactive dialogue context, the high inertia effectively simulates both tension and collaboration between the light and us. The difficulty in control challenges the user, indicating the user does not have full authority in the interaction. Yet, the inertia facilitates maintaining consistent cranking speeds, allowing our cranking input to support the light's autonomy. In other words, the wheel's high inertia can be less useful to obtain an intended value from cranking, but it can be useful to foster ongoing engagement; either the light or the participant invites each other to adapt.

Limitation

There are several limitations in this study. Firstly, certain control setups are not identical because of the nature of the iterative prototyping. For instance, we did not continue to involve the saturation control in any other control setups after implementing **Dis-GRINDER - CD - 0…255 - Clip - Colour (saturation).** As it pointed out its limitation of the experience, we avoided repeating it and focused on the setups that were closer to our study aims. More insights could have been shown by actively combining the approaches; for instance, turning the handle multiple times in the wrapped value range in **Dis-HANDLE** to compare it with **Con-HANDLE - CD - 0…255 - Wrap - Brightness,** turning the handle once with the relative form of control in **Con-HANDLE** as opposed to **Dis-HANDLE - CD - 0…255 - Clip - Brightness,** or implementing a mirrored control with **Con-HANDLE** as opposed to **Con-GRINDER - CD - 0…255 - Wrap - Brightness- (b) mirrored control (1 cycle).** Secondly, when comparing the crank handles, the small crank handle and the grinding wheel have noticeable differences regarding their form factors. These can significantly impact how we translate the input and how we evaluate the experience. For instance, the handheld crank handle is directly mounted to the sensor and the input is directly exerted, while the grinding wheel is firstly mounted to the table and the cranking input is indirectly transmitted to the sensor. Despite the difficulty in the direct comparison between the mounting setups, it is important to note that this study rather aimed to explore how inertia and form factors affected experiences across distinct setups. As an indicative study, the chosen approach reflected how each crank type works in practice and eventually provided a range of insights for further studies. Thirdly, the evaluation was relied on by the researchers. Although the embodied experience can be argued with their expertise, involving more participants could further support the findings.

Overall Conclusion

Traditional button switches are binary, just by being on or off. However, cranking makes us exert physical effort and feel the momentum. It engages our entire body by making us feel things like rotational angle, speed and inertia. The findings in this study showcased the potential of crank-based input in the context of a direct form of control and interactive dialogue. The experiments showed that cranking direction (**CD**) feels more controllable than cranking speed (**SP**). In the **CD** setups, the logic measures the crank handle's position change. It can obtain an intended value, although it could not go beyond being a simple and predictable simulation like a light switch or knob. By contrast, the **SP** setups require continuous input over time. Turning the small crank handle that does not have inertia makes it difficult to attain an intended value, while the grinding wheel setup can be controllable due to its high inertia. In the interactive dialogue context, our body plays a part in the experience. The physical sense, like inertia that is felt through our body, enriched the experience and encouraged active immersion. The study highlighted the potential in the setup where the fast cranking speed accelerates the light's movement whereas the cranking in a different direction decelerates it. The grinding wheel's inertia facilitates continuous cranking at a consistent speed to support the light's movement, while it introduces difficulties in control, leading to tension between the light and us. From these explorations, the study found that the limitations in one context- a direct control- can be useful in another context- creating an interactive dialogue between the light and the user.

Future Research

This study can be extended in several directions. Firstly, the setups mentioned in the limitation can implemented to complement the comparisons that we did not cover in this study, such as obtaining an intended value by turning the handle multiple times in the wrapped value range in the **Dis-HANDLE** setup, implementing a relative form of control within the clipped value range in the **Con-HANDLE** setup, and implementing a mirrored control with the **Con-HANDLE** setup**.** Secondly, one can involve more participants in the setup **Con-GRINDER - SP - 0…59 - Wrap - Movement** to support our findings and discover the aspects we may have missed in the evaluation. Additionally, one can extend **Con-GRINDER - SP - 0…255 - Clip - Brightness-(b) Influence the light's behaviour** where the light changes its brightness level at intervals, simulating a breathing effect. However, the implementation was difficult to understand, because the directional speed was not applied and it only provided additive progression in the value. From there, one can implement the setup where the directional speed decreases the intensity of the value to clarify the input's impact on the light. We note that another type of animation not only for the brightness control but also for the movement control is possible as there are numerous ways to represent the autonomy of the light. To conclude, we hope this study took a primary step to bring the physical values of cranking into the domain of interaction design; cranking is more than a switch.

Archive

34 Experiments (YouTube Playlist)
https://www.youtube.com/playlist?list=PLNpF0Xk_eFYuRV0Xeg8D0qQzwZbbRuDkT

All the trials; 74 videos (YouTube Playlist):
https://www.youtube.com/playlist?list=PLNpF0Xk_eFYuCT2cQcx8vI4IaC2FPSgtj

Codes
https://drive.google.com/drive/folders/1pywhHx3kXW1VOW5t38Rjcr2VMPPidZO3?usp=share_link

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