Can Asynchronous Kinetic Cues of Physical Controls Improve (Home) Automation?

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Abstract

The proliferation of automation in domestic environments places a demand for their mechanisms to be self-explanatory to the layperson with no specialist training. The current work proposes a design approach that introduces kinetic cues to familiar physical user interfaces (i.e., throw switches) that will allow human-automation communication without the need of additional displays (e.g., screens, voice). Here, we report an exploratory study on how naïve users (n=15) responded to and interacted with a semi-automated lighting system that actively sought to engage them with itself; by through unprompted movements of its switch. Qualitative analyses of recorded interactions and semi-structured interviews reveal that users were surprised by unfamiliar automation and that kinetic cues promoted discovery of the system's mechanisms and mitigated human-out-of-the-loop problems.

Keywords

Human-automation interaction, human-in-the-loop, design methodology

1. Malfunction Or Automation

Regardless of technological advances, automation will never be omniscient. It might be able to adapt its control policy to certain pre-specified contextual variables (e.g., time-of-day, typical user preferences). Nonetheless, automation is unlikely to ever be able to read user intentions with absolute certainty [4]. This means that automated system behaviour that is incompatible with user intent could be perceived as a malfunction or an annoyance, which could eventually result in disuse [17].

For instance, many of us have experienced being plunged into sudden darkness in a foreign toilet, simply because its lighting system had determined, from our stillness, that we no longer exist. The modern world, which currently contains a mix of analog and automated systems, presents users with a novel inconvenience. We can no longer infer that this undesirable system state is simply a malfunction. Instead, we have to perform system testing. While we wave at possible motion detectors (or attempt to engage any other possible sensors), we secretly yearn for an analogue switch instead that would communicate our desired system state with unambiguity. In fact, we would have preferred to have been "consulted" on our desires beforehand [15].

In this paper, we report a study that explores solving this problem by modifying familiar interfaces to draw users into engaging and collaborating with automatic processes. More precisely, we investigated if asynchronous kinetic cues could be applied to the physical throw switch of a room's lighting system to help users to understand the automated and strange lighting behaviour in an unfamiliar environment and, ultimately, to collaborate actively with it—as opposed to being subject to it. We report the subjective experiences of participants who had to solve a puzzle (i.e. "Devil's Knot") in a room with two sources of light, which served separate functions: a ceiling light supported visibility of the task and a UV lamp revealed suggestions for solving the puzzle. A light switch allowed manual toggling between the two lighting conditions and could be manipulated at any time. However, participants were naïve to their ability to switch to the UV condition. Deterministic automated behaviour switched between the lighting conditions every three minutes. However, only one participant group experienced

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a light switch that would perform autonomous physical switch flipping (i.e., kinetic cues).

1.1. A New Approach – Asynchronous Kinetic Cues

In the early 1960's, Mayall and Shackel used the cybernetic concept of the control loop to describe how human-machine interactions would evolve, given rapid advances of automation technology [11]. A basic control system without automation can be defined in terms of: (1) Controls or information input channels (IN), (2) displays or information output channels (OUT) that, when connected to IN to constitute a referential context [6], gives feedback to an (3) operator (USER), who connects to IN to close the loop. This results in three vertices that are connected through directed edges to form a triangle (figure 1, left; pink edges highlight cues that can be perceived by different sensory systems).

Automation excludes the USER by establishing its own control loop, which comprises a central control unit (CCU), SENSORS, and its own hardware interface (PORT) to manipulate OUT. All edges to and from the user are rendered superfluous as well as their corresponding vertices (figure 1, middle left), which creates the human-out-of-the-loop problem [5]. By using servo controls, especially in such cases where there is a mechanical binding, e.g. steering wheels (figure 1, middle right), it is possible to provide feedback to the user via the controls, which is now able to function as a display [12]. However, this does not specify for potential malfunctions [13], nor does it facilitate collaborative human-automated behaviour. Our approach exploits the fact that automation disrupts the formerly analogue connection between IN and OUT in several ways: It enables feedforward, allowing anticipation, and emphasis feedback. Exaggeration can be implemented to supplement missing bodily cues, which we are used to from human-human interactions. Furthermore, deliberate breaks [6] can help to re-invoke the interaction paradigm [8] in order to reallocate attentional resources.

1.2. Transverse problems in automation?

The issues presented here are not only observed in the pervasive deployment of home automation. It has also been observed in safety-critical domains, e.g. aviation, with severe consequences. In fact, mode confusion is a critical factor to the recent Boeing 737 MAX crashes, wherein pilots could not determine if the airplane was suffering a malfunction or responding to a false inference [15]. This has led to revised requirements in task sharing between automation systems and pilots, whereby new displays are now recommended to indicate the reliability of automation's inference [5]. Do displays that communicate this explicitly with visual text and auditory speech achieve this? Ultimately, displays are limited in that they do not explicitly direct users to affordances of the environment that control state changes.

To reiterate, a physical throw switch is both a display and a control device that additionally is constitutively referenced with a corresponding output. Its orientation indicates system state and it affords the opportunity to change the system state. Physical elements are still commonly deployed in many devices, both analog and digital, and users are familiar with how these display and control system state. However, while the approach in automation of implementing synchronous movement of control devices and outputs serves as "potentially available" feedback – which also is a standard in aviation (e.g. autopilots of airplanes move the controls as if an invisible pilot were doing it) – it is not necessarily "attended to properly" [13]. Can asynchronous kinetic cues serve to effectively

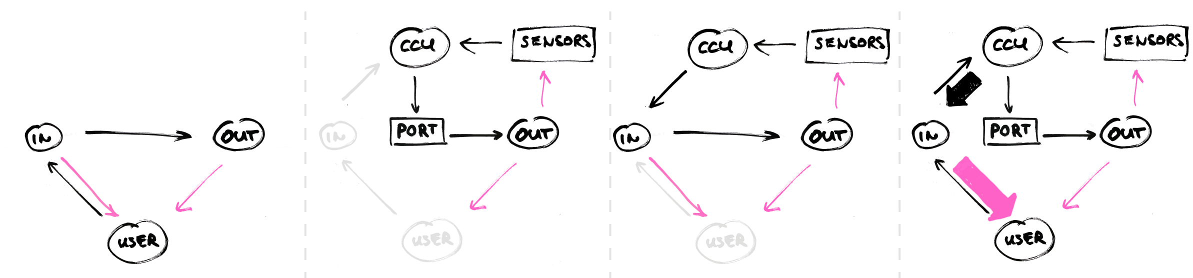

Figure 1: Basic cybernetic control loop with an analogue connection between input and output (left); automated system that utilises its own interface (PORT) to manipulate its output – no human in the loop (middle left); an automated system utilising servo controls that synchronise input and output (often mechanically; middle right); asynchronous kinetic cues exploit the decoupling of input and output.

display automation's intention to change the system state, so as to afford the user the opportunity to reject or accept this intention and therefor reduce suspected malfunctions? Before answering this question it is necessary to first know how naïve users perceive familiar control devices (i.e. the switch) that might move in an unfamiliar way. Our study aims to fill this gap.

2. Methods

The current study was designed to address the overall question of: *How people who have never been in touch with such a system (that is vying for their attention) react to and interact with it?* Therefore, we prototype a mock home automation scenario that manipulated the interface either expressed kinetic cues or did not. Specifically, we looked at the decisions of users to either take manual control over the automated system and intervene, or simply to be subject to its behaviour.

2.1. Material

The setting was designed to be inconspicuous. Our participants did not perceive or experience any unfamiliar hardware. Instead, customised electronics that controlled automated movement of the physical switch and lighting behaviour were kept out of sight. The light switch was actuated (i.e. triggering a kinetic cue) by a hidden motor (100:1 Micro Metal Gearmotor HPCB 12V) that drives a forward/backward conveyer attached to the switch's rocker on the inside. All the electronics are on a printed circuit board (PCB), which is hidden in the cover. It carries a microcontroller (ESP8266 on a ESP-12F module) that monitors the status of the unit so that it can sense if it was flicked manually or that it has to power the motor and trigger a cue; it also contains a network stack for wireless communication with other units, i.e. the outputs. The motor driver (L9110S) and a voltage regulator (NCP1117) as well as a couple of capacitors and resistors are also soldered onto the PCB surface. The device is powered via an adapter by mains supply. For the two outputs (ceiling and desk lamps), relays were implemented that were located close to their respective lamp. The wire that was originally interrupted by the switch was bridged for the contacts to be decoupled from mains supply. The contacts of the original switch are connected to the microcontroller. Each unit (switch, ceiling light and desk lamp) had its own controller, which could communicate wirelessly.

For software, the current implementation utilises the Message Queue Telemetry Transport (MQTT) protocol over a wireless local area network. It is based on the architectural publish-subscribe pattern, which is the standard for many internet-of-things applications. Locally stored commands for kinetic cues of individual units can also be manipulated during run-time via an API (setup using Node-Red). One of the units stores the program that directs the logic of the system, functioning as a central control unit (CCU). It also functions as the broker and distributes messages, so-called topics, across the corresponding units. In addition, each unit runs its own internal programme to manage incoming topics and trigger the corresponding actions, or publish own topics back to other units via the CCU.

2.2. Setting

The study setting is based on the rationale that a system behaves automatically to support objectives that are shared with its user. All participants (n=15; 9 females, 6 males; median age=36 yrs) had the task to solve a wooden puzzle in a room that was fitted with our lighting

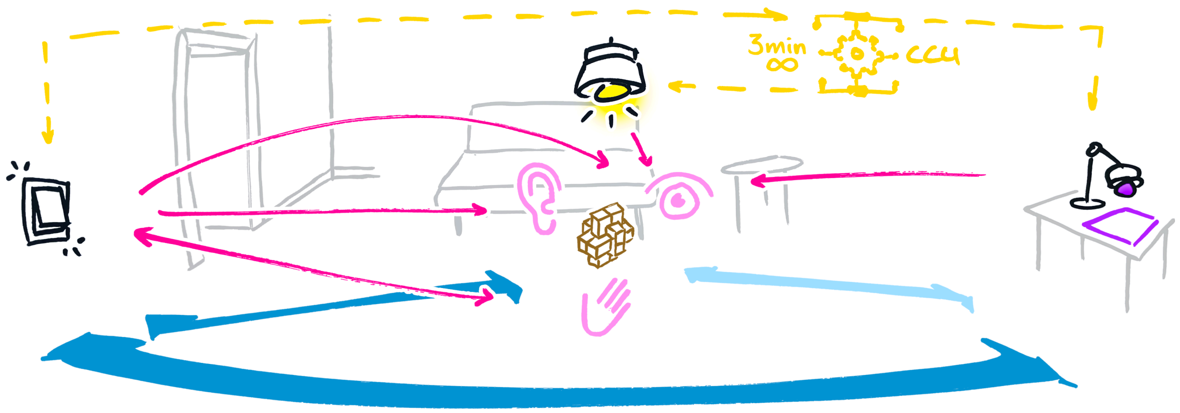

Figure 2: Kinetic cues in action – **bidirectional dialogue** between **users** and **system components; motion profile of the sample (additional paths of the experimental group); communication between components; the puzzle, i.e. devil's knot; invisible instructions;** surrounding furniture.

system. They were naïve to the real purpose of the experiment and informed that they were participating in a cognitive experiment that investigated puzzle solving.

Figure 2 depicts a study schema. Participants experienced a living-room environment with a couch and a neighbouring side table. The table held a disassembled wooden puzzle (i.e., Devil's Knot) in a small box that had to be reassembled. The lighting system consisted of three components: A ceiling light, a desk lamp with an ultraviolet (UV) light bulb, and a (single pole double throw) wall switch that toggles between either light source. The UV desk lamp was stationed on a separate table, within walking distance from the puzzle, that had instructions to solve the puzzle that were only visible under UV light. The wall switch was next to the entrance door. The study began when the user entered the unlit room, which also initiated the automatic alternating activation between the ceiling and the UV desk lamp every 3 minutes.

Modifications to the interaction design were introduced from participant 9 onwards, which are referred to as phase 1 and phase 2. First, phase 1 provided a note, halfway through the hidden instructions, which informed participants that the switch was operable at any time. This was removed in phase 2 to evaluate if kinetic cues could be implicitly understood. Second, the lighting system alternated between its two modes every 40 seconds in phase 1 and every 3 minutes in phase 2. Third, two different kinetic cues were employed in phase 1, which were increased in phase 2 to seven cues, with escalating intensities every 30 secs. Fourth, operating the switch manually also deactivated the automatic alternation in phase 2 whereas in phase 1 only the timer is reset and automatic alternation continued – apart from switching the light analogous to the switch state in both phases.

Thus, the critical condition involved the use of asynchronous kinetic cues and there were two versions (Compare Figure 3 below and above wavy line). The baseline condition was an ordinary automated lighting system (OAS) with a non-moving switch whereby participant 7 served as a control for phase 1 and participants 14-15 were controls for phase 2. In phase 1, the switch performed a mid-time cue and a pre switch cue (see grey arrows; Figure 3), which respectively correspond to cue #1 and #6 in phase 2. The repertoire of kinetic cues was expanded to seven different sequences of automated switching operations. They are described in Table 1 and can be viewed at this video link.

2.3. Procedure

Participants were welcomed in a separate room, signed a consent form with instructions, and filled a short questionnaire on demographic information and to describe their general affinity

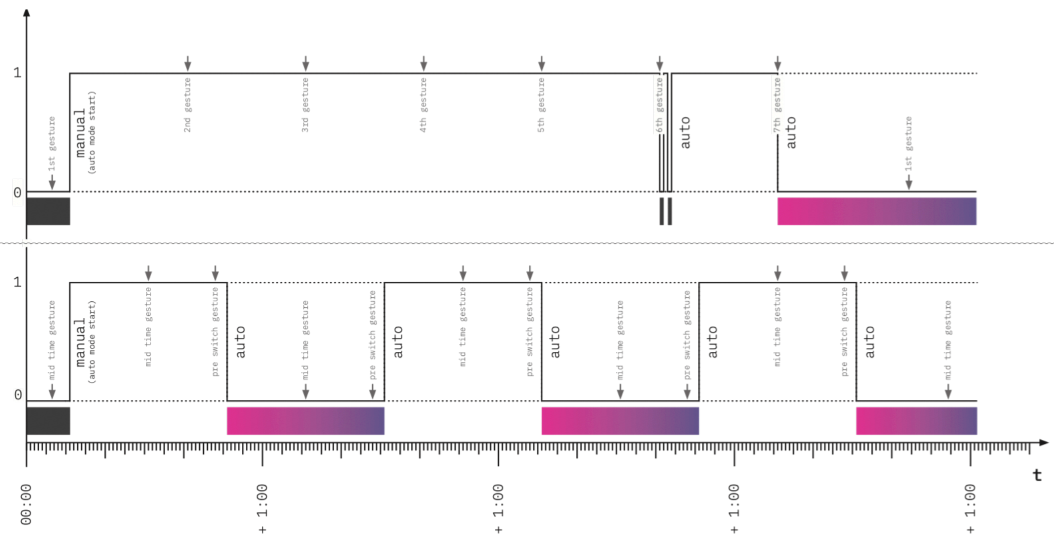

Figure 3: Diagram depicting the two timing algorithms of the experimental group in phase 1 (below wavy line) and phase 2 (above). Solid lines depict the ceiling light, dotted lines depict the UV light, which alternate (0 is off; 1 is on). The pink-purple (ultraviolet) bars correspond to exactly these alternating light conditions as an additional visual element (black bar ≙ darkness; pink-purple bar ≙ ultraviolet light; no bar ≙ bright light). Grey arrows indicate the triggering of a cue. Note: The control group runs on the same algorithms that turn on and off the light with the only difference being that the switch does not move (not pictured).

Table 1
Description of kinetic cues with links to video example

Cue # - Timestamp	Intended Meaning
#1 - @2s / mid-time cue	Tentatively raising awareness for a novel interface concept ("Excuse me!”) / Half the time is over.
#2 - @32s	Intended communication: Making acquaintance with the novel feature of a familiar interface; (“This is your switch.")
#3 - @62s	Reassure that this is an intentional act rather than a defect. ("Yes, I am talking to you.")
#4 - @92s	Getting a bit excited. ("I want you to flick me.")
#5 - @122s	Getting very excited. ("Come on, flick me!")
#6 - @148s / pre-switch	Explaining the constitutive assignment between switch and light by flicking the switch and the relay on and off analogously each second twice. / Four second countdown before switch.
#7 - @182s	Ordinary automated behaviour of doing things for the user + maintaining the constitutive assignment between the switches states and the lights states. ("I'm giving up...")

towards technology and relationship with automated systems. Participants were introduced to the think-aloud method [2] and prompted to apply it during the study. They were provided a picture of the room and instructed to sit on the couch and to look into the small box. Typically, the study was terminated by the experimenter as soon as the participant adapted to the automated timing or established a clear strategy of switching between the two lighting conditions to solve the puzzle. This session was video-recorded. Finally, a semi-structured interview was conducted and audio recorded where the real purpose of the study is also revealed.

Video-recordings of the experiment were summarised as so-called interaction plots – a diagrammatic visualisation of time (X-axis) and the flow of (inter-)actions (Y-axis): Information on the subject’s movement (interaction with either switch, puzzle, or instructions), changes of the lighting conditions and whether these have been triggered automatically or manually, and the different kinetic cue. The think-aloud comments are added as well. This allowed relationships between these factors to be visually inferred. The interviews have been transcribed with the help of Rev AI’s Speech-to-Text API. Specific passages were assigned to the respective situations of the experiment via time stamps to enrich these with more details.

3. Findings

The following findings are based on subjective interpretations of interaction plots, which are derived from the video-recordings and semi-structured interviews. They are presented here to provide insights into user predispositions to system automation as well as to inform future development and design of asynchronous kinetic cues of interface input elements in order to improve automated systems.

All participants (except P6) used the switch when entering the unlit room. This indicates that most participants assumed that flipping the switch controlled the room’s lighting. All participants expressed surprise when the lighting mode changed automatically and some attributed antagonistic intent to the lighting system. P4 expressed “That is mean!” before realising the revelation of the hidden instructions. P7 said “Argh, miese Rinde!” [East-German idiom; something like: “Argh! Perfidious!”] when the ceiling light came back on whilst reading the hidden instructions. This highlights the problem that automated technology can behave without warning and be perceived as uncooperative. The overall initial impression of the system did not differ with regards to kinetic cues.

P10 and P11 did not realise that activation of the ceiling lamp alternated automatically with the UV desk lamp. Thus, unlike all other participants, they assumed a malfunction that they tried to repair. P11 asked out loud "Is there a motion detector?" and tried waving. Both P10 and P11 eventually reverted to a familiar interaction paradigm to repair the ceiling light by flipping the switch, which Ju [8] refers to as "reiteration". Thus, if unexpected system behaviour benefits the situation, it is interpreted as intentional. The same behaviour is either interpreted as a malfunction or is ascribed to automation if it does not benefit the situation.

In contrast to the experimental group, none of the control participants ever touched the switch after their initial interaction. This suggests that they assumed that they were unable to interfere with a a lighting system that automatically alternated between the ceiling light and UV desk lamp. Participants of the experimental condition in phase 1 ultimately knew they could use the switch. However, they sometimes waited for the system to do so, even if it took more time than it would have taken to work the switch; here, they demonstrated satisficing. The three control participants always waited for the entire time interval (thirty seconds or three minutes respectively) to pass, scheduling their actions to suit the respective light mode, even if it was not the desired one. This also suggests satisficing, if they were aware of the possibility to use the switch; if not, that could be ascribed to complacent behaviour.

Kinetic cues were perceived as irritating at a first glance. Still, participants who experienced kinetic cues experimented with the switch. ("Uh, does UV turn on when I press here? [flicks the switch] Ah, okay, that's intriguing too, of course! [flicks the switch a couple of times]" P5). In the experimental condition, eight out of twelve participants manually flipped the switch and thus learned the functional principle of the lighting system.

P8 mentioned the clicking sound early during the experiment and correctly inferred that it related to the mechanism of the lighting system and learnt to use the switch as per desire. Others (P6, P9, P10, P11, P12) first associated and attributed the audible clicks of switch-flipping, not to intentional communication of the lighting system but, to more familiar sources, namely a background camera. It took participants multiple consecutive cues to grasp the concept. Hedonistic responses to these were mixed.

Based on anecdotal evidence, the modification in phase 2 that intensified clicking frequency is likely to have accelerated a realisation of the system's mechanism.

4. Conclusion

From a first glance, kinetic cues are not self-explanatory and can be irritating for novel users. We propose that the interpretation of the meaning is only the final of four necessary steps to the understanding of a kinetic cue: 1. Conscious detection; 2. Localisation; 3. Attributing intentionality; 4. Assigning meaning. Moreover, the meaning of a kinetic cue is always derived from the context rather than from the specific sequence of clicks. Hence users learn to understand a system from experience and training – the more familiar one is to a specific system and its cues, the less important become the latter two steps.

In our study all users were naïve even to the fact they are part of a human-automation interaction in order not to spoil the observation of people's first impression. In this respect kinetic cues were tested under harsh conditions and are potentially more effective in scenarios, where users are already familiar with this kind of technology. In such a case a user would have to detect and localise the specific input and only combine the internalised meaning with regards to the context, e.g. the light switch next to the entrance door of my apartment triggers a kinetic cue each time I open the door but left on a light. If I myself was not the designer of my home automation system I would have to see what happens when I flick the switch, otherwise I know it anyway and can react accordingly. In that sense kinetic cues are most effective in affording people to take manual control but less in the sense that these improve the understanding of the system by their very nature.

The timing is a crucial aspect both for the design of a single kinetic cue (especially for an interface as simple as a switch, the sequential alternation of its two distinct positions over time is the only way to prolong a signal and thus vital to detection and localisation) and especially within the greater context of the system. Only by decoupling input and output (allowing feedforward), we give users the possibility to act rather than react and agree jointly on a solution.

Our results do not allow unambiguously concluding that kinetic cues improve automation magically. We see the main potential in maintaining situational awareness and the coordination of human-in-the-loop systems. The greatest advantage of a systems like this is that it can be operated entirely manual or fully automated (at least to the degree the system naturally supports); but also any level of automation (LOA) in between may be realised. This is great for the transition period we are in until full-automation may finally understand our desires.

Moreover, if well-known issues of automation from such fields like aviation also appear in a domestic environment, do the results of our solution also apply to those?

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