THE SINGING SHOWER: A MELODY-SENSITIVE INTERFACE FOR PHYSICAL INTERACTION AND EFFICIENT ENERGY CONSUMPTION

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ABSTRACT

This paper proposes an interface based on melodic input, encouraging a user to sing in order to interact with a device. We describe the early stages of designing and prototyping a sound-reactive shower, which is controlled by a user singing to control the flow of water. We then discuss the implications of this design with regards to energy and resource efficiency, as well as being a form of provocation and experimental interface design. Interaction design has an important role to play in facilitating sustainable behaviour in the household. We propose that sonic interfaces such as this can contribute to this area of work, and that an interface based on melodic input can be used to seamlessly activate and deactivate a system while using hands and vision to accomplish other actions and reducing energy consumption. In this paper, the prototype is described, evaluated and results are discussed. Finally, directions for future work and extensions of this system are proposed.

1. INTRODUCTION

The resources used in the home environment are, for the most part, invisible [1]. Whilst in the past the energy for a household would have been generated inside the home with fire, coal, or peat, in modern times this is no longer seen, heard, or felt. The electricity to power our appliances and the gas burned to create our heating and hot water is in many ways now an abstract concept. Although many would like to lower their resource use, it can be hard to quantify or even imagine what it means [2]. The study described in this paper is part of a larger project, Sound for Energy [1], which proposes that sonic interaction design can offer one method for addressing this issue.

This paper describes the design of the *Singing Shower* - a system enabling a user to control the flow of water in a shower with their singing. We will describe the development of the first prototype as well as our initial user tests. Results are then discussed and directions for future research are suggested.

The Singing Shower is in some ways a experimental interface for engaging with home energy use and water consumption through sound. However we will argue that the prototype, even in its current early stage, manages to address and challenge fundamental issues in interface design and home resource use, through the medium of playful sonic interaction.

2. BACKGROUND

The design of how we interact with everyday objects can strongly contribute to promoting a more sustainable behaviour [3]. This is increasingly true as homes begin to be equipped with smart meters and IoT based Home Energy Management Systems (HEMS), which can provide information, awareness, and control possibilities to end-users [4]. However, research has shown that existing visual displays of energy costs and savings are not effective [5,6]. Studies have found that current displays are designed for an unrealistic “resource man” interested and able to micro-manage energy resources, rather than a real user living in a “domestic mess” [7]. Instead, users need to be inspired and have fun in order to be engaged [8].

While several studies (e.g. [9–11] have attempted to overcome issues of engagement and design, only rarely has non-speech sound been considered as primary mode of communication and interaction (e.g. [12–14], and only recently has this area emerged as a topic in its own right within the sonic interaction design and sonification fields [15, 16]. Research has shown that everyday sounds such as knocks, footsteps or vocal sounds, are extremely informative despite being perceived as mundane, with the advantage of requiring little conscious attention or effort (e.g. [17–19]. Additionally, researchers have identified an unpopulated design space in the domestic soundscape for novel sonic interactions (e.g. [20]. These novel sonic interactions can address issues related to sustainable behaviour by harnessing existing domestic sound behaviours and attitudes (e.g. singing happily under the shower), while at the same time increase awareness, control and playfulness. Developing sonic interactions that are familiar, personal and even loved by their users could facilitate both long term behavioural change and a feeling of satisfaction.

In this paper, we present a prototype of a sound-reactive shower, which is operated by a user singing to control the flow of water. This sonic interaction makes use of the personal and playful experience of taking a shower, while at the same time promoting an efficient way to control water consumption.

The starting point is the concept of a so-called *Navy Shower*. This is a technique developed in military envi-

[1] https://soundforenergy.net

ronments, particularly on naval ships, in order to conserve water and heating to maximise efficiency in the use of resources. The main strategy of a Navy Shower is to turn the flow of water on only when necessary for rinsing the body, and turn off the water while applying soap [21]. This can have significant impact on resource use, with at least one study claiming a 95% reduction in average water usage, leading to a potential saving of 15,000 gallons per year per person [22]. Domestic Hot Water (DHW) usage has also been identified as a key area of high energy use, remaining relatively consistent in recent decades whilst other forms of heating have been made more efficient [23]. The Navy Shower approach offers a proven method for addressing this area of energy inefficiency in the home.

The shower offers an opportunity for novel sonic interactions through the medium of singing. Singing in the shower is a well documented phenomenon, with references dating back to at least the 14th century [24] and certainly occupying a clear place in popular culture. A number of potential reasons have been proposed for its popularity, often referencing the unusually sonic characteristics in bathrooms due to size, tiling, and generally more reflective surfaces than elsewhere in the home.

Additionally, singing in the shower is clearly a playful experience. Playfulness and ludic experiences have a unique role in human lives [25]. We play to learn new things, create new memories, and develop new values and understandings. Recent research is starting to investigate how we can design new interactions harnessing the power of playfulness [26–28]. In line with this approach, in this project we aim to leverage hedonic and playful opportunities to encourage greater resource efficiency.

Sound, and in particular the human voice, can function as a powerful tool for computer interaction and physical interface control. Voice control systems have been under development since at least the early 1980s (e.g. the VOTAN V5000 system [29]). Voice interaction has more recently become essentially "domesticated" within modern homes [30–32], with products such as the Amazon Alexa or Apple Homepod. However this domestication comes at a cost, as the seamless experience offered by modern voice control is both physically and ethically encumbered [33] as it relies on massive servers, raises significant privacy concerns, and creates issues related to bias (in regards to accents, vocabulary, and fluency, etc) [34–37]. In this project we are thus attempting to retain the advantages of voice control (e.g. freeing hands and eyes), whilst avoiding its problematic aspects.

The device presented here regulates the flow of water in the shower in response to a user singing. This sonic interaction method enables efficient and touch-free control of water, simplifying (and possibly augmenting) the Navy Shower approach to efficient resource control.

The result is a playful, experimental, and in some ways provocative device that builds on prototyping approaches that engage with the "messy, intimate, and contested aspects of everyday life" [38, p. 2549].

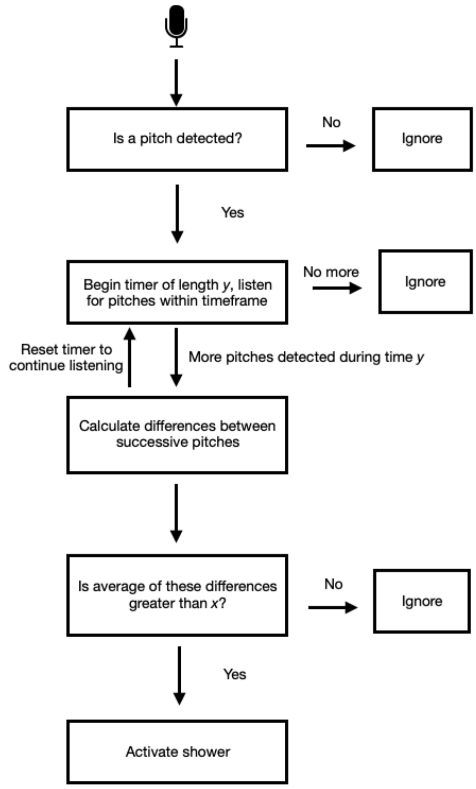

Figure 1. Flow chart indicating the structure of the machine listening code

3. SYSTEM DESIGN

In order to address these challenges we have chosen to develop a melody-reactive binary control system which detects only whether or not a user is singing. This deceptively simple concept opens a number of questions in terms of technical design, interaction design, and social and cultural considerations. Limiting the input to melody and the output to a binary state allows the system to completely avoid any recording, bypassing any potential privacy issues. The system can be entirely self-contained (and un-encumbered), whilst retaining the major advantages of voice control in terms of hands-free usage and seamless touch-free interaction.

In this design, the binary control is dependant on continuous singing - the water flows only whilst the singing is occurring. This is an important distinction from clap detectors, for example, which function as latching switches. This is a deliberate design choice that aims to reinforce the physical connection between the user and the water flow, with their voice providing the metaphorical "power" required to shower. This is designed to provide an embodied experience of energy consumption [39, 40], and to make visible (and audible) an otherwise invisible process of intensive resource use [2].

3.1 Melody Detection Software

For our first prototypes we built a system in Pure Data (Pd)[2] running on a Bela microcomputer. The code can be found on the author's GitHub page.[3]

We developed a machine listening system that reacts mainly to a series of different recognized musical pitches within a short timeframe. This approach biases the system towards short melodic phrases with relatively large differences in pitch. This was deemed acceptable for this prototype as it feels playful and reacts quickly - in addition there are a number of variables (e.g. timeframe length, size of differences in pitch) that can be adjusted during testing.

The prototype contains an electret microphone connected directly to the Bela Mini microcontroller (using a resistor attached to 3.3v power[4]). The Pure Data code running on the Bela is using the *sigmund~* object to listen to the incoming audio. If a pitched note is detected on the audio, this pitch will be stored in an array and a timer will be activated. This provides the first level of filtering on the audio, as the pitch will only be detected above a certain threshold of recognizability (set using the *threshold* variable on the *sigmund~* object), therefore a fair amount of non-musical sonic activity will be ignored immediately.

Following this, any further notes that are detected within the timeframe (variable y in Fig. 1) dictated by the timer will also be stored in an array. The difference in MIDI note value between each successive note is calculated, as is the average of these differences. If this average is above a certain value (variable x in Fig. 1), and the timer is still activated (meaning that pitched notes are still being detected), the digital output connected to the shower solenoid is set to 1 and the shower turns on. If not, the output value is set to 0 and the array is cleared.

3.2 Hardware

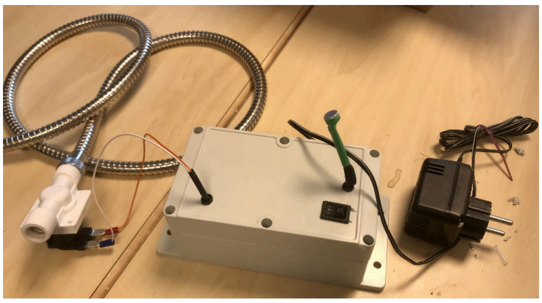

Figure 2. Hardware prototype

On the Bela, the output from Pd is sent to a digital pin, which is connected to a relay. This relay controls the state of a water valve solenoid, which is placed in between the hot water mixer and the shower head of a standard shower.

The majority of the electronics are housed in a waterproof enclosure in order to protect it from moisture, apart from the electret microphone which protrudes from the box. A large rechargeable battery powers the Bela, however this was not sufficient to power the solenoid, and no satisfactory method for integrating the water valve into the enclosure was found. Therefore the water solenoid was hung outside of the enclosure for testing, and a standard 12V wall power supply was used to power the relay for this initial prototype. A short demo of the singing shower can be viewed online.[5]

4. EVALUATION METHODS

A pilot user experience test was devised in order to evaluate how users would react to a melody-sensitive interface, and to test the robustness of software and hardware. The prototype was installed in a shower in the department bathroom at KTH in Stockholm. Eight participants (M=3; F=5; average age: 31) were recruited from within the department and consisted mainly of students and staff. They were given a brief description of the prototype and asked to stand near the shower and sing to control the flow of water for as long as they felt comfortable. For this initial test, the users were not asked to take a shower. The participants were then left alone to complete the task. Audio recordings were made of their tests, and following that they were asked to complete a User Experience Questionnaire (UEQ)[6] [41] and answer in writing a few open ended questions about the experience.

Prior to this testing, the prototype was installed in the lead author's shower for several days, in order to evaluate the hardware and software and to create video documentation. The author and one other member of the household used the prototype to successfully take (singing) showers.

5. RESULTS

5.1 System Functionality

The eight participants interacted with the system for an average of 3.5 minutes each (min duration 1 minute; max duration 7 minutes). On average the water flow was turned on 18 times, of which 13 were deliberate. On average the flow was stopped 13.5 times, of which 10.9 were deliberate. Thus the success rates of the machine listening and mechanical control system were 72% for switching on and 81% for switching off.

An analysis of the recordings reveals that participants tested the system in a number of ways other than singing a tune. They tried to whistle, speak, clap, fool the system by playing music from a mobile phone, and test single pitches by saying a single pitched vowel - in addition one trained classical singer tried a number of modern extended singing techniques. Clapping, single pitched sounds vowels, and music did not turn on the system. Speech sometimes activated the shower, whistling seemed to confuse the system, and the modern extended singing techniques had mixed results.

[2] `https://puredata.info`
[3] `https://github.com/yannseznec/singing-shower-software`
[4] `https://forum.bela.io/d/62-cheap-electret-microphone-how-to`
[5] `https://www.youtube.com/watch?v=8UUXhprBt7U`
[6] `https://www.ueq-online.org`

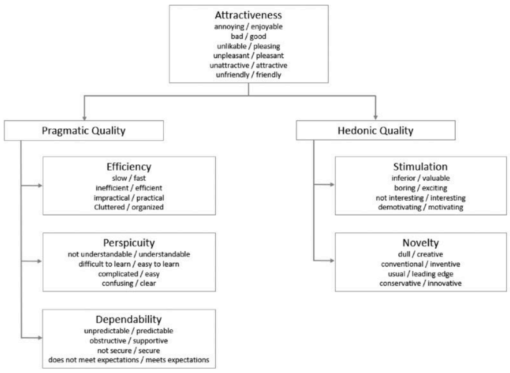

Figure 3. UEQ scales: image from the UEQ Handbook in `https://www.ueq-online.org`

5.2 User Experience

The User Experience Questionnaire provides validated scales to measure six user experience factors which describe both Pragmatic and Hedonic qualities of an experience: Attractiveness (Do the users like the experience?); Perspicuity (Is it easy to learn what to do, and get familiar with?); Efficiency (Can the task be achieved without unnecessary effort?); Dependability (Does the user feel in control of the interaction?); Stimulation (Is it exciting and motivating?); Novelty (Is the experience innovative, creative, interesting?). In total 26 scales are used: 4 scales contribute to each factor with the exception of Attractiveness which uses 6 scales. A summary of the scales can be seen in Fig. 3.

The main advantage to using such a tool for quantitatively measuring the main aspects of user experience is that it provides a simple but robust way to compare results between this initial version and future versions of the system. Additionally results are automatically set in relation to existing values from a benchmark data set containing data from 21175 persons from 468 studies concerning different systems and products.

While results from this pilot test should be taken carefully given the low number of participants, the UEQ questionnaire can provide an initial snapshot of the main trends in the user experience of the system.

From Fig. 4, we can see that Attractiveness and Hedonic qualities are rated positively, while the Pragmatic quality is considered less positively. If we look at the six contributing factors: Novelty and Stimulation are considered very positively, while Dependability and Efficiency score quite low. Perspicuity does not score sufficiently high, however it seems to be less problematic. When comparing against the benchmark provided by the authors of the UEQ, Attractiveness scores just below average, Stimulation and Novelty are above average and excellent respectively, while Perspicuity; Efficiency; Dependability are all in the range of the 25% worst results. It seems clear that, while the Hedonic qualities could get through even when using a very initial prototype, Pragmatic Qualities need further iterations of the system to be perceived to be functioning always as expected.

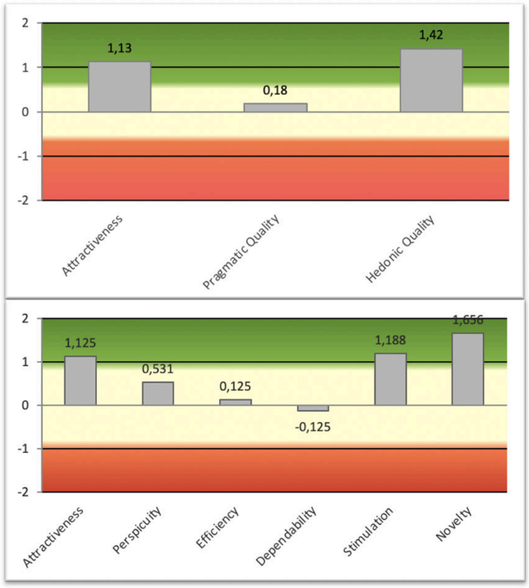

Figure 4. Summary of results: Top Graph - Attractiveness, Pragmatic Quality and Hedonic Quality; Bottom Graph - Attractiveness; Perspicuity; Efficiency; Dependability; Stimulation; Novelty

When looking at the results for the individual items within the factors (Fig. 5), we find that the system scored very high for friendliness, inventiveness and innovation, then follows interest and excitement; while the system scores negatively for predictability, support of the task, and security (i.e. it is not always sure that it would work as expected).

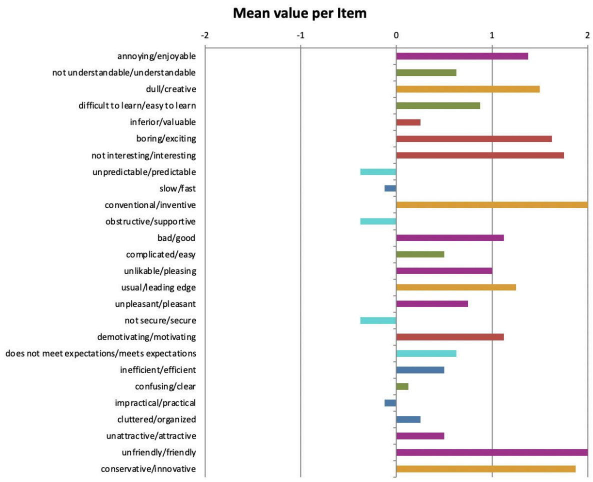

Figure 5. Results by Items

5.3 Open Ended Questions

After the test, we asked the participants to describe their experience, to describe how they thought the singing controlled the flow of water, and whether they would feel comfortable to use such a system at home. Finally they were free to add any further comment.

The experience was described as interesting, intuitive, joyful and energising. One person commented that the system worked as expected most of the times. With regard to control participants commented that it was pretty smooth, and easy. They noticed some delay between the start of singing and the water flowing, additionally they thought that a minimum sound level was required for the singing to be recognised as quieter singing seemed to be missed at times. One participant commented: "I tried to make some different kinds of singing to see if it affected the shower in some way, but did not really understand if it did, or if it just reacted to sound and was a bit buggy." In terms of using this system at home participants noted that they would not have a problem, and might prefer it over a regular shower and that it was fun, however final usage might depend on the mood of the day. One person noted: "I don't think that I would like to have it in my house. It would be quite exhausting to sing all the time you want the water to run." One participant expressed concern about having the system connected to the internet, recording sounds (they were not aware that the system does not need internet connection or recording sound).

Finally, we asked one person, other than the first author, to take a normal shower with our system. We report here the feedback which is promising and appears to align with the design goals:

> The way the water responded to my voice gave me the sense that I was physically powering the shower with my own breath. For the first few seconds I had to experiment a little with the volume at which I was singing, but once I got the hang of it, it felt easy. I was surprised by how little I needed the water to be on to clean myself effectively. But I was also surprised by how much I enjoyed the experience and how empowering and fun it was to sing to control the shower.

6. DISCUSSION

Despite being an initial prototype, the system demonstrated great potential as a playful interface. This was reflected both in the UEQ results for the Hedonic Qualities and Attractiveness, and the user feedback and audio recordings made during testing. It is also reassuring that Perspicuity - which refers to learnability and ease of use - despite not yet scoring very high, does not seem to be the major culprit in the relatively low score of the Pragmatic Quality. As the technical robustness is improved, we speculate that learnability and ease of use will consequently improve. Overall, these results reflect the cohesive design framework, and in particular the clear reference to the existing cultural phenomenon of singing in a shower seems to be appealing. The test gave us a broad sense of how users would enjoy the system, test its limitations, and how comfortable they were with the idea of controlling the flow of water with their voices.

The technical functionality of the prototype was more than sufficient for this initial test, with significantly more successful interactions than failures. The spectrograms (Fig. 6) from the audio recordings of the test clearly demonstrate the system functioning as designed, with melodic activity resulting in the shower turning on, and remaining on until the user ceases singing.

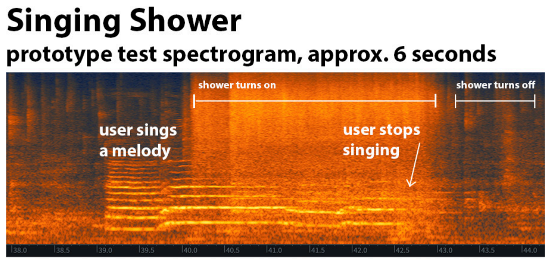

Figure 6. Spectrogram illustrating how the singing turn on the shower, while the absence of singing turns it off.

Further testing is required in order to fully evaluate the machine listening software. The tests in this paper were all conducted using fixed parameter values that were set when developing the system in the bathroom of the first researcher. It is likely that, for optimal performance, the system would need a calibration procedure when moved into another bathroom that takes into account the different shower system and room.

In the short term, a number of improvements are planned with regards to the hardware prototype. Notably, the powering system should be redesigned in order to control the solenoid valve from a battery, avoiding the need to plug the system into the wall. The solenoid valve should also be integrated into the enclosure for stability and ease of connection, and general improvements can be made to the containment system to make it more robust and usable inside the shower. A number of the failed attempts to activate the shower were also likely due to a low volume of singing, which could be addressed both with an automatic input gain system and with better physical placement of the microphone.

No matter the approach, we aim to carry out more systematic evaluation studies as the system is improved. Our tests showed that if a user is deliberately attempting to experiment with the system by using different sounds it can be difficult to assess whether to classify the resulting flow of water (or lack thereof) as a success or a failure. Similarly, some system failures are more frustrating or noticeable than others - if the water does not turn on when expected, for example, this is can be considerably more frustrating than if the water turns off unexpectedly.

With regards to the melodic sensing system offering a more privacy-sensitive approach to machine listening, there remains a challenge in terms of user experience design. This was illustrated by the user who voiced some concerns around possibly being recorded in the shower, despite the system being designed specifically to avoid that approach. Any future system will need to account for existing negative user associations with audio surveillance.

Perhaps most importantly, real-world testing is required, with an improved hardware prototype installed in a home, and with participants tasked with using the system to take a shower. Through a study of this kind, we will be able to establish whether the enjoyment of the experience is long-lasting, whether some people would enjoy the system more than others (for example, children more than adults), whether there is an effect on energy consumption, and whether the experience increases awareness about energy consumption in the household. However transferring the testing to a home environment is a major challenge as they are of course deeply private spaces [42], and showering is a particularly intimate activity. The improved and more robust prototype will be designed with this type of in-home testing in mind.

7. FUTURE WORK

The tests described in this paper were relatively easy to set up due to the simple and standardized nature of the showers both in the author's home and within the KTH department, with a mixer containing a single 1/2-inch pipe fitting. A larger scale test would likely need to consider different types of showers, and how a prototype could accommodate an array of different fittings.

In the future we might consider including an AI-based approach [43] to the machine listening system, with a model built on a large corpus of recordings of people singing. This could improve the accuracy of the singing detection, however, it may bring back some of the ethical and privacy issues we aim to avoid.

Overall, this prototype represents the first output of a larger project looking at sonic interactions in the home, and how they can intersect with issues of energy consumption and resource efficiency. Whilst the relationship between singing and showering is particularly clear, we plan on continuing to explore the wider usability of melodic sound as a method for control in the domestic environment, as well as the use of a physical metaphor representing energy use.

As this project forms a part of a larger set of research regarding resource use, it will also be crucial to look more holistically at the overall benefits of introducing a new technology to mediate the use of hot water. Does, for example, the inclusion of a new electronic device (with associated lithium ion battery, silicon board, integrated circuits, etc) outweigh the benefits of potentially lower hot water use? The prototype described in this paper is still early stage and it was therefore not appropriate to attempt this analysis yet, but it should form a part of the review of any device that is made ready for more intensive testing. An analysis of this kind could draw inspiration from comparative life cycle assessments in projects like the Solar Powered Website [44].

8. CONCLUSION

We have described a project that brings together playful design methods, physical and sonic interaction design, and energy efficiency considerations. It does this by leveraging an existing common domestic behaviour in a surprising way. The results reported here of the evaluation of the initial prototype are promising, and we have outlined how we intend to develop the project in the future.

Whilst it is tempting to consider the potential viability of the Singing Shower as a product that could be installed on a wider scale, it is also worth acknowledging that it will likely encounter deeply entrenched resistance for a number of reasons. It is an interface that requires more physicality and active engagement than normal, all in the service of providing an admittedly less luxurious experience in the shower (a moment of a day which is often seen as special and relaxing). In this sense the project functions similarly to the "threshold devices" described by Michael and Gaver [45] by providing a physical metaphor that can open up discussions about resource use and our relationship to comfort and luxury. We consider this prototype, and the future iterations planned, both as a viable product which combines accessibility, usability, and interaction design considerations with sustainability issues, as well as a form of speculative and provocative design which challenges conventional framings of home energy use [46].

Acknowledgments

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