Defining and designing ‘Interaction’ in Human-powered products

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Abstract— **Human-Power Products (HPP) are perceived as an alternative to battery generated products [1]. The design element in HPP attempts to engage people into interaction, performing new behaviors of generating your own power. Nowadays, HPP applications are widely used from portable electronics to large-scale installations, successfully harvesting ‘free energy’ from peoples daily movements. This paper presents findings from a study of everyday interactions with human-powered products (HPP). This study created a taxonomy of existing HPP, exploring how a ‘design’ element induces new interactions, sometimes by stealth, while exerting human muscular energy. The taxonomy dimensions are based on an investigation of identifying different attributes of how a user accepts ‘perceived behavior control’ [2] over human-power. The paper also briefly discusses the process of investigation conducted with 10 UK householders, trialing a newly designed HPP prototype, for the duration of 1 week. It was aimed at understanding how motivations were acquired, how feedback helps to interact, and provide real qualitative insight into HPP interaction the householders experienced.**

Keywords- Human-powered products, Interaction Design, behavioural change

I. INTRODUCTION

The interaction embedded in HPPs communicates directly to users an environmental benefit of harvesting your own energy as an alternative power source; a clean energy. One such interactivity, power generation in HPP, may be interpreted as a feedback system where the ‘consequences’ communicate to people about what our body can do. Currently, challenges in using HPP are related to the reduction of labour involved in power generation. Recent ideas around inducing a motivation when using HPP focus on designing its user-centeredness in providing ‘fun’ and ‘playful’ experiences. Yet, the question of what level of psychological awareness, either conscious or sub-conscious interaction, are involved in applying human-power remains uncertain. To begin to define these different interaction modes, the study contrasts different types of HPP with the socio-psychological factors informed by theoretical aspects in the field of behavioral change. The study suggests that there are three factors to consider in designing HPP for wider use. First, real-time *feedback* should be in place to engage users into a discourse of generating alternative energy, linking the related activity with an energy-conscious attitude. Secondly, the dimension of *delegation of control* highlights the notion that ‘design’ undertakes an important role in inducing interaction between the system of HPP and user; thus creating individuals as autonomous agents that link the subject of enquiry to become internalised, to practice long-term behaviors. Finally, how designed interactions of HPP can generate intrinsically motivated behaviors where they are self-determined to perform the action in fully volitional modes.

Defining a clear meaning of human-powered products was the foremost step for this research since there are three broad definitions found from literature reviews. Firstly, Dean [3] featured most of the examples of human-powered products from her book which incorporates rotary motion, in other words; the mechanical output such as pedal power or treadle. Secondly, Jansen defines the concept as “electric products powered by muscular work from the user” which focuses on the conversion of muscular work of the user into electricity [4]. Thus, Jansen additionally sub-defines between ‘human-powered’ and ‘energy system’ in order to clarify that the power is generated by ‘human muscular work’ within a system of ‘a technical artefact designed for converting the effects of human muscular work into electricity’ [4]. The last definition is defined by scholars [5, 6] as ‘parasitic harvesting’ utilising human body movement as a power source for electronic devices. The idea of ‘parasitic harvesting’ is to generate power in an ancillary way while people are doing things like walking or typing, or to pick up energy from the body as it breathes, pumps blood and generates heat [5]. The power source is scavenged indirectly from the user’s everyday actions or might be subconsciously generated by the user. Dean defines this concept as Passive Energy Harvest, “a collection of human energy, whether mechanical, thermal or chemical, to generate power, given a person’s minimal or unconscious effort” [3, p. 53].

II. THE HPP INTERACTION MATRIX

From monitoring concepts of HPP from wider sources, the research developed a 'Human-Power Products Interaction Matrix', as shown in Table 1. This Matrix is configured around two dimensional axes; the horizontal axis representing the cognitive mode of user interaction between conscious and sub-conscious power generating; the vertical axis shows the type of output in HPP - either (bio) mechanical and electrical. The purpose of this Matrix was to classify and analyse different attributes of HPP to create taxonomy of HPP, identifying the dimensions of 4 design spaces.

TABLE I. HPP INTERACTION MATRIX

	Sub-conscious Interaction	Conscious Interaction
Mechanical	 Figure 1. Pendulum Watch	 Figure 2, Maya Pedal
Electrical	 Figure 3, Sustainable Dance Floor	 Figure 4, Baygen FreePlay Radio

- **Mechanical + Sub-conscious interaction:** Harvesting energy from a sub-conscious mode of user muscle energy, parasitic harvesting, and convert into mechanical power output (e.g. Fig. 1, Pendulum Watch [7])

- **Mechanical + Conscious interaction:** Harvesting energy from the conscious mode of user muscle energy, direct force exertion, and converted into a mechanical power output (e.g. Fig. 2, Maya Pedal's Bicilicuadora – the bicycle blender [8], or a bicycle)

- **Electrical + Sub-conscious interaction:** Harvesting energy from the sub-conscious mode of user muscle energy, parasitic harvesting, and converted into electrical power output (e.g. Fig. 3, Sustainable Dance Floor [9])

- **Electrical + Conscious interaction:** Harvesting energy from the conscious mode of user muscle energy, direct force exertion, and converted into electrical power output (e.g. Fig. 4, Freeplay Radio [10])

A. *Mechanical (Bio) / Electrical power output*

The starting point of configuring a vertical axis onto this Matrix was derived from the notion that not all HPPs are powered by electricity. Jansen's definition of HPP is a 'non-conventional power source' focusing on products featuring a conversion of muscular work into electricity [4]. This is where the definition may counter against Dean's argument that a 'conventional power source' historically used to be a human-power [3], e.g. a gramophone. Consequently, HPP can be defined as any products powered by human physical interaction which either has an output of (bio) mechanical or electrical functions. The best example of the vertical axis of the Matrix will be the bicycle. It directly amplifies human muscle energy into mechanical work to produces a velocity (or rotational power, .e.g., Fig. 2) which then enables the user to travel a distance. These types of non-electrical HPPs still exist in everyday life, and include. Coffee Grinder, can openers and hand whisks as further examples.

B. *Conscious / Sub-Conscious Interaction*

When designing a HPP, the vital challenge might be how to reduce the labour around power generation, avoiding real or perceived fatigue to the users. Experience of such fatigue can be regarded as 'perceived behavioural control' [2]; evaluating the dis/advantages of consequences resulting from exerting human-power. Although fatigue or stress is difficult to measure, the motivation of the user may be determined by the user's wider perceived benefits such as price saving, fun, environmental friendly, no battery, and feel-good factors. These external and internal factors are perceived as incentives of using HPP. The research was able to define and differentiate types of interactions into two modes of human-power input, conscious user and sub-conscious user interactions. Examples of such differentiation can be observed from Fig. 3 and 4. The BayGen Freeplay Radio requires a one handed cranking physical motion to wind up the spring which then unwinds to power the motor to supply sufficient electricity [10]. In this interaction, the users utilise their muscle power to apply a kinetic energy consciously by cranking. In other words, the user is in a cognitive and conscious mode of generating energy through a body motion and human muscle exertion. On the other hand, other examples characterised as 'sub-conscious interaction' are devices of HPP that utilise energy being generated by human physical movement arising from a sub-consciousness of daily 'interactions'. For example, parasitic harvesting technologies that scavenge power, or from an interaction with a third device (e.g. dynamo installed on top of a revolving door). The example shown in the Matrix is the Sustainable Dance floor [9]. This concept utilises the fancy footstep pressure energy (produced by dancing movements) into kilowatts to power other basic utilities. The design harvests energy in an entirely ancillary way.

C. 'Fun' Interaction

Perhaps the idea of using *parasitic* harvesting methods originated from resolving the issue of requiring a deliberate effort to input the human-power, the 'labour'. Hence, some recent works suggest harvesting human-power from playful or *fun* energy which can be seen as the most effective technique to persuade others for perpetuating its use. The Playpump, Fig. 5 is an interesting example, although this product does not have any electrical output, comprising two functions from one application of physical kinetic energy [11]. The purpose of this design is to provide a clean drinking water facility when children have fun spinning on the merry-go-round, clean water is being pumped from underground into a 2,500-litre tank. The concept attempts to induce using human-power from, above all, a spontaneous enjoyable activity. Any 'labour' in terms of energy generation in this design is compensated by 'Fun'.

Figure 5. Playpump [11]

Global companies such as Sony have carried out research in the field between interaction design and HPPs. They are seeking ways to generate electricity as users 'play' with the devices, adding aspects of fun, playfulness, curiosity, ambiguity and unusual practices in use [12]. One of Sony's concept products include the Spin N' Snap (Fig. 6), a digital camera that is electrically charged by placing two fingers in two separate holes and spinning it around a few times to allow a charge. The concept shows how interaction design expands its role in providing more intriguing 'perceived behavioural control' [2] over their human-power input. People are drawn into an interaction that enables them to experience the consequences of generated power which is derived from a 'fun' interaction. Although the level of consciousness involved in this design application is still immeasurable, the strategy is to induce charging behaviour through interaction design that is beyond the more traditional techniques such as cranking. This is not to argue that techniques like a push button or simple winding motions do not provide intriguing experiences.

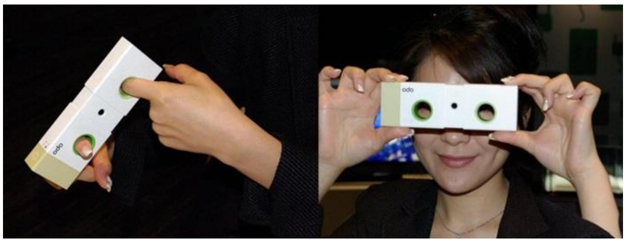

Figure 6. Sony Odo Project, Spin N' Snap Digital Camera [12]

While many parasitic harvesting technologies are concentrating on scavenging human-power from a 'sub-conscious' mode of power input, most HPPs attempt to draw motivation for applying human-power in a discrete mode of interaction. The 'fun' activities involved in HPPs are themselves intrinsically rewarding during 'play' and arguably they are in a 'conscious' mode. In the same context, it can be seen that the availability of incentives (free electricity) may enhance such intrinsically motivated behaviours. The discrete nature of interacting with the device arises when the user consciously plays with the 'fun' feature, but the method of transforming the human-power into other form of energy such as a pump or electrical function is sometimes scavenged in sub-conscious mode (Stealth mode).

III. MAINTAINING THE USE OF HPP

A. Motivation

In deliberating the 'fun' interaction, it was observed that such techniques do generate 'playful' features. However, it can be seen from the Sony Odo and Playpump projects that they have two distinct interactions to enable physical contact for inducing this 'fun' aspect. For the Sony Odo, it is a re-design of applications that enables the user to have more 'fun' exerting human-power, and transfers rotational power into a dynamo. The Playpump engages the user into a 'fun' interaction via a third device; the merry-and-go. For both, the research found challenges in justifying these concepts into attributes for 'Mode of Human-Power Input'. From a motivational perspective, both draw users into a 'fun' interaction; however, it is difficult to make any firm argument whether the mode of interaction is conscious or sub-conscious. Arguably, the challenge lies in how a system of feedback communicates with the user. For instance, the output of 'Spin N' Snap' (Fig. 6) provides consequential feedback by applying Human-power in a relatively short period of time by allowing them to take a photo with pre-generated electricity. For the Playpump, the feedback system provides the user with a velocity of riding the merry-and-go, and users are drawn into an activity of 'play', but the device does not provide any feedback of how much water is being pumped. The Playpump can be 'played' as a standalone device in addition to its role as a device for generating water or electricity. In other words, the motivation for using such a device may also be based on user-centeredness, i.e. designed around 'fun' and 'play' interactions. As argued by Jackson [13], when behaviours are strongly regulated or reinforced by external factors, in this case the 'fun' aspect, it may show a weakness in linking the related attitude of 'power generation'. In view of its complexity, the 'fun applications' were considered to be extended into the third dimensional axis which describes other qualitative measures, leading to the question of; What motivates a user to use the HPP?.

B. *Delegation of Control*

Most of the parasitic harvesting or sub-consciously interacting HPPs deal with increasing the efficiency of power output by 'delegating' control over power generation merely to product; they are 'Self-powered devices' [5]. They can be seen as 'devices' where the control over power generation is delegated towards the system of the product. For example, it can be seen that the Sony Odo delegates control of human-power generation to the user who makes a conscious decision via exerting muscle energy - the 'design' element is 'fun'. For the Playpump, the 'fun' interaction arises when users are consciously 'playing' with the merry-and-go, but the delegation of control for water pumping is parasitic. In other words, users may have delegation of control over 'fun' but a 'perceived behaviour control' may only exist in the reinforced external factor of 'playing' with merry-and-go rather with the whole system of HPP; thus enabling the transfer process of human-power into a functional energy output.

C. *Feedback*

However, this does not mean that people are always in a sub-conscious mode or unaware about the generated energy. By having such a system of feedback, it may be insufficient in bringing changed behavior, but rather it can invite them into 'thoughtful engagement' [14]. Whether the designed application in HPP utilises conscious or sub-conscious interaction, it becomes more apparent that the system of feedback will play an increasingly important role in engaging users into a discourse of generating alternative energy. It is argued by scholars that frequency of feedback plays imperative role and as well as the design factor for instigating behavioural change [14, 15]. The bicycle, for example, provides real-time (live) feedback that shows how human-power (pedalling) amplifies the energy into velocity. HPP in this category typically provides a 'direct' experience of learning how human-power transforms into functional power output. Conserving energy, solely relies on users who are 'autonomous decision-makers' [16].

IV. HPP INTERNALISATION MODEL

Maintaining the changed behaviour may not require any external motivations such as incentives or emotional stimuli if intrinsic (psychological) motivations are sufficiently situated at an early or decision-making stage. However, it has been argued that attention should equally be given to how new behaviours become 're-routinised' and perpetuated as long-term in daily practice [17]. It is argued that interventions of behavioural change which use persuasive techniques or other forms of extrinsic motivations are likely to fail as they become no longer available [18]. In comparison, intrinsic motivations that are gained by direct experience do not merely depend on the effect of interventions using extrinsic motivations or external factors. Deci and Ryan [19] argue that intrinsically motivated behaviours do not depend on reinforcements since undertaking activities that are interesting in itself are intrinsically rewarding. They proposed that intrinsically motivated behaviours are based on people's needs to feel competent, self-determined, and autonomous. This is due to the fact that people feel subsequently less motivated as they feel controlled by extrinsic motivations. Deci and Ryan hypothesise that extrinsic motivations can be controlled invariably to the extent to which they are self-determined. To support this argument, they created the concept of 'Internalisation' where behaviours affected by external regulations are internalised through the processes of introjection, identification, or integration. As people show a lack of desire in changing behaviours, it can be controlled by either external regulation (by others) and by introjected regulation that is administered by an individual. Identified regulation refers to people feeling ownership of behaviour, and thus be more autonomous. Finally, such integration enables the behaviour to perform in fully volitional mode of action where they are self-determined and its 'internalisation' become most effective [19].

The complexity involved in the psychological mode of 'Fun' interaction led the researcher to consider how motivation plays a crucial role. Based on initial findings, it is suggested that the system of feedback could allow new behaviours to be sustained and maintained over a period [20] and be controlled by the autonomous individual [16]; the user. By linking all three dimensions (axes) with respect to social-psychological aspects in a behavioural model, a 'HPP Internalisation Model' is proposed (Fig.7).

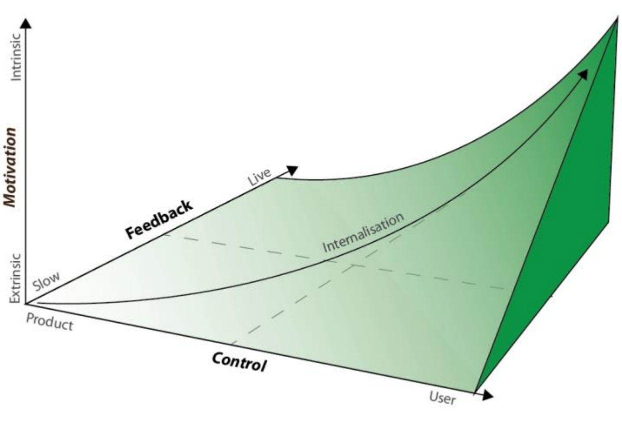

Figure 7. HPP Internalisation Model

V. THE USE-PHASE

The three dimensions are yet to have any real data to support their effectiveness in both theoretical and practical terms. The research focused on an empirical study to understand how users perceive these 'design elements' of HPP. A series of events were organised, and prototype built, to demonstrate and reflect on these theoretical hypotheses. In order to associate the hypo-theoretical model with new HPP development, a case study was conducted to show the process of implementing 'HPP Internalisation Model' by designing and testing the concept with the actual user.

Prior to the design and deployment of the new concept, a pilot study was conducted against 10 randomly selected individuals from the University. The aim was to understand the general perception of HPP via an existing human-powered radio and to identify problems while they interact with human-power system. All participants were briefed to undertake other activities like reading or talking on the phone while they listen to a radio for a duration of 30 minutes. Interestingly, all participants commented on difficulties of not having a 'feedback' display which allows them to know the remaining run-time. Participants' expected run-time of the fully charged radio varied from 15 minutes to 8 hours whereby its actual capability was 8 minutes from 1 minutes of cranking. As they cope with these uncertainties, they experienced the difficulties in assessing the outcome (available functioning time) over effort put in to exert the human-power which may affect their motivation. This resulted in the majority of participants viewing the device as an emergency rather than possible, adaptation towards everyday use. According to E. M. Rogers, a decision concerning adoption or rejection of such innovation is made when information-seeking activities have reduced the uncertainty about the innovation's expected consequences [21]. However, in this case, the lack of feedback system has resulted in having insufficient delegation of control of power-generation.

A. *Home User Study*

Between January and March 2013, 10 UK households across the Nottingham district were recruited to trial new prototypes of HPP (Fig. 8). The participants were recruited through a survey that was conducted prior to the deployment of the device. One of main purposes of the survey was to gather qualitative data aimed at understanding how people feel about potential adaptation of using HPP as main resource to power domestic electronics i.e. powering a TV through an energy bike. 26.8%of survey respondents showed an interest in participating. As a result, a final 10 UK households were selected as participants through a sampling process, a group having a real motivation towards adopting the device in their own domestic environment – the case study is named 'Home User Study' (HUS).

The new HPP system consists of an energy bike that is wired to a 'white box' which includes the battery unit to conserve the generated energy. The digital display on the front panel indicates the unit of conserved power. On the side panel, there is a power inlet that the user can also use. Although, this device was 'fake', meaning that the device does not include any real components to operate as human-powered, it was designed to cut off electricity when the unit of battery reaches at 'zero'. Inside the box, there is a meter that is only accessible to the researcher which measures the total input (generated power) and output (consumed electricity) units. The 'decrease' rate of the unit was based on information collected from energy bike experts. For example, in order to watch a TV with consumption rate at 100 W for 1 hour, total of 360 units are required which can be achieved through approximately 30 minutes of pedaling.

Figure 8. New HPP Prototype

It was important for this research to select a common electronic medium that is common amongst those 10 households. Televisions are one of the largest electricity consuming appliances; therefore, it was selected as a product to be powered by the new HPP system (the e-bike). The HUS was scheduled for three visits at an interval of 1 week. On the first visit, a smart meter was placed to measure the total electricity consumption and hours of watching TV. The following week, the e-bike system was deployed with an instruction showing how the system works. At the final visit, the meter readings were presented to participants, comparing previous measurements prior to the e-bike deployment. Along with the data presentation, semi-structured interviews were conducted in relation to understanding how their motivations changed throughout the trial. The interview focused on the substantive areas of HPP research in regards to the actual use-phase of which little is researched. It attempted to identify theoretical perspectives of using HPP as an everyday product, and its potential as a harvesting alternative to purchasing electricity from the power grid.

VI. CONCLUSION

This paper represents the first attempt to create a taxonomy of HPP which discusses the cognitive mode of user interaction involved in power generation. From reviewing relevant literature in the field of behavioral change, it suggests three elements to consider when designing HPP for inducing wider use of such systems. The qualitative evidences obtained during the semi-structured interview are currently under further analysis. However, it was found that the majority of people have responded that the motivations during the experiment were not merely influenced by external regulations or rewards, but they were determined through additional behavioral modes such as self-satisfaction, e.g. 'I saved energy'. Also, the feedback was perceived as significantly useful in having levels of control- where people find the size of power consumption as well as available run-time generated by exerted human effort. However, it is recommended that a longer duration of prototype use is required in future research. Such research could add further detail to HUS and explore whether the process of internalisation differs across different types of households. Additionally, it could provide more in-depth qualitative analysis using ethnographic techniques to explore the dynamics of HPP use, not only on a single appliance like a TV, but induce new practices and behaviours of powering existing and emerging electronic devices in the home..

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