AC 2012-3394: CREATING ACTIONFUNCTION DIAGRAMS FOR USER CENTRIC DESIGN

Ms. Shraddha Sangelkar, Texas A&M University, College Station

Shraddha Sangelkar is a doctoral student in the Mechanical Engineering Department at Texas A&M University. Her research advisor is Dr. Daniel A. McAdams. Her research focuses on the universal design, data mining and application of association rule learning, and product platform design.

Dr. Daniel A. McAdams, Texas A&M University

Daniel A. McAdams is an Associate Professor of mechanical engineering at Texas A&M University. His research and teaching interests are in engineering design with focus on concept generation, bioinspired design, and design methods for inclusive design product lines.

Creating Actionfunction Diagrams for User Centric Design

Introduction

Users are perhaps the most important aspect of consumer product design. There is a significant body of research about the ways to measure and achieve user-friendliness in a product. A customer-driven approach to product design aims for greater user comfort and better product experience. Design tools that keep the user in mind during early stages of design can greatly improve the usability of the end product.

Systematically breaking down a product into its constituent functions as is done in functional modeling allows its designer to focus on one function of the product at a time. Functional modeling allows designers to abstract the functionality of a product irrespective of the product's form or shape and is well received as a product representation framework within the design research community. This paper introduces the concept of an actionfunction diagram, which builds on the framework of functional modeling. Actionfunction diagrams incorporate the associated user activities in addition to the functions and the flows in a functional model. Thus, the actionfunction diagrams allow designers to effectively model the user-product interaction.

In an actionfunction diagram, an activity diagram and a functional model are combined into a single graphical representation. Product functions are modeled using the Functional Basis and user activities are modeled using the International Classification of Functioning, Disability and Health (ICF) lexicon. The ICF was established by the World Health Organization and provides a standardized lexicon and taxonomy for the description of health and health-related states. This paper explains the application of ICF lexicon for creating actionfunction diagrams.

Modeling the user interaction with respect to the product is a crucial step in product design. The activity diagram is widely recognized as a tool to model user activities in relation to the product. However, the activity diagram stands by itself and does not reflect how a change in user activity affects product function; the user activities in an activity diagram are independent of the product functions. A product representation framework like the actionfunction diagram overcomes the limitations of the activity diagram, enhances the effectiveness of functional modeling, and provides a means to incorporate user-product interactions in the early stages of design.

This paper details the procedure for creating actionfunction diagrams with a case study on a can opener. The details of the procedure are based on the authors' experience in creating, applying and teaching both actionfunction diagrams and functional models. This paper further serves as guide for instructors teaching actionfunction diagram modeling. Additionally, design students, product designers, and future researchers can benefit from this research. The paper also provides a checklist for building actionfunction diagrams and lists the caveats for creating consistent actionfunction diagrams.

Background

Functional modeling

A functional model is a representation of the process by which the product being designed will be functionally implemented [1]. Functional modeling abstracts the overall functionality of the product and decomposes that functionality into its constituent elements, allowing the designer to focus on partial solutions for enhancing the creativity.

To represent product function, this work uses the Functional Basis and its associated flow based functional modeling methodology [2,3]. The Functional Basis is a thoroughly evaluated and accepted method for representing product function [4-6]. Nagel and Otto offer good summaries of discussions on how to use the function based modeling method [1, 7].

Activity diagram

An activity diagram is a network of high-level user activities encompassing the life cycle of a product from purchasing to recycling or disposal. Activity diagram is also known as a network of parallel and sequential tasks carried out by the user, where parallel activities lead to parallel product functions. An activity diagram gathers customer needs in the initial phases of product design and helps establish the boundaries of the product or system under consideration.

The main objective of an activity diagram is to ensure that the designer is aware of the entire set of customer needs during the life cycle of a product. Generally, the list of activities does not include design or manufacturing related activities. Although improving purchase and disposal of a product can significantly impact the design of product, those user activities are not considered in this discussion of the activity diagram for brevity.

To easily understand the actionfunction diagram a good understanding of the activity diagram is useful. Otto and Wood provide a detailed explanation of the activity diagram creation process [1]. A formal representation for describing varied user activities improves consistency and communication among different designers. For the user centric design, user activities can be modeled using ICF that is explained in the following section.

ICF Lexicon

The International Classification of Functioning, Disability and Health (ICF), established by the World Health Organization provides a standardized common language for the description of health and health-related states [8]. The ICF provides alphanumeric codes and definitions for a terminology that allows a uniform description of human functional ability and limitation. The ICF is originally intended to serve as a statistical, research, clinical, social policy and education tool [8].

Sangelkar and McAdams have applied the ICF lexicon for universal design to model user limitation [9]. ICF can be used not only to denote user limitation but also user ability. Based on prior research, ICF serves as an excellent and well-defined lexicon to describe varied user activities related to product design [9,10]. In this paper, the application of the ICF is extended to model the activities for user-centric product design. The following discussion explains the ICF in further detail as it applies to product design.

The ICF is classified in two major parts, namely *i)* functioning and disability and *ii)* contextual factors. For our application, we focus mainly on the functioning and disability part, which further divides into two components: *a)* body functions and structures and *b)* activities and participations. Body functions and structures are useful from biomechanical perspective of product design. However, for the description of user activities related to a consumer product, the component activities and participation seems appropriate. Sangelkar has detailed the structural organization of ICF as applicable to universal design [10].

The ICF uses an alphanumeric system of classification. The letters b, s, d, and e are used to express the body functions, body structures, activities and participation, and environmental factors, respectively. The letter is followed by a numeric code; first digit of which is the chapter number followed by two digits signifying second level of detailed classification. In certain cases,

there might be a third and fourth level of classification specified by one following digit each. For example, *d4* is mobility related activities, where *d450* to *d469* cover walking and moving; *d450* is the activity of walking, *d455* is the activity of moving around, and *d4552* is the activity of running.

Qualifiers are placed to the right of a decimal point following the alphanumeric code [8]. The qualifier for activities and participation component is a capacity or performance qualifier indicating the level of ability or limitation. The qualifiers are specific to the product being designed; hence the qualifiers are not included in the discussion to maintain generality.

Formally modeling user activity with the ICF is still a developing method and requires some interpretation. Table 1 lists the ICF terminologies with its alphanumeric code and the formal ICF definition. An interpretation of the ICF terminologies as user activities for product design is also listed in the last column of Table 1.

For example, the activity grasping *(d4401)* is defined as using one or both hands to seize and hold something, such as when grasping a tool or a doorknob. In the context of product design, grasping represents the activity to hold an object or the handle for operation of the device. The activity speaking *(d330)* has the implied meaning of giving voice commands for activation of devices. Other general activities like carrying, moving and handling objects *(d449)* and moving around within the home *(d4600)* are used while defining the peripheral activities.

Note that during the activity modeling effort, the designer can move back and forth between different levels of the ICF. For example, *d415* and *d4452* are at different levels of specification, or fidelity, within the ICF taxonomical structure. The goal is to model the user activity as precisely as the ICF lexicon allows rather than to use a consistent level within the ICF.

Actionfunction diagram

An actionfunction diagram is a product representation framework for modeling the user-product interaction. Actionfunction diagram is a formal representation used to analyze the interplay between user and product in the early stages of design [10,11]. In an actionfunction diagram, an activity diagram and a functional model are combined into a single graphical representation.

Table 1. Alphanumeric code, definition and interpretation for some ICF terminologies

ICF term	ICF code	ICF Definition	Interpretation for activity modeling
Picking up	**d4400**	Lifting or taking up a small object with hands and fingers, such as when picking up a pencil.	Pick up hand held products
Grasping	**d4401**	Using one or both hands to seize and hold something, such as when grasping a tool or a door knob	Hold an object firmly in hand for required operation
Manipulating	**d4402**	Using fingers and hands to exert control over, direct or guide something, such as when handling coins or other small objects.	Complex hand activities that requires manipulation with fingers
Pulling	**d4450**	Using fingers, hands and arms to bring an object towards oneself, or to move it from place to place, such as when pulling a door closed.	Pulling with finger, arm, hand (grasping of the object is included)
Pushing	**d4451**	Using fingers, hands and arms to move something from oneself, or to move it from place to place, such as when pushing an animal away.	Pushing with finger, arm, hand (can be performed with a closed fist)
Reaching	**d4452**	Using the hands and arms to extend outwards and touch and grasp something, such as when reaching across a table or desk for a book.	Reach out or extend outwards to position an object using hands
Turning	**d4453**	Using fingers, hands and arms to rotate, turn or bend an object, such as is required to use tools or utensils.	Turning knob or tap. Rotate something with hand
Carrying, moving and handling objects	**d449**	Carrying, moving and handling objects, other specified and unspecified	For importing and positioning an objects
Communicating with-receiving-written messages	**d325**	Comprehending the literal and implied meanings of messages that are conveyed through written language (including Braille).	Reading signs and symbols for directions
Pushing with lower extremities	**d4350**	Using the legs and feet to exert a force on an object to move it away, such as pushing a chair away with a foot.	Pushing with leg force
Sitting	**d4103**	Getting into and out of a seated position and changing body position from sitting down to any other position, such as standing up or lying down.	Getting into and out of a seated position
Standing	**d4104**	Getting into and out of a standing position or changing body position from standing to any other position, such as lying down or sitting down.	Getting into and out of a standing position
Moving around within the home	**d4600**	Walking and moving around in one's home, within a room, between rooms, and around the whole residence or living area.	Approaching household appliances and positioning oneself with respect to it.
Transferring oneself	**d420**	Moving from one surface to another, such as sliding along a bench or moving from a bed to a chair, without changing body position.	Moving from wheelchair to seat or vice a versa
Speaking	**d330**	Producing words, phrases and longer passages in spoken messages with literal and implied meaning, such as expressing a fact or telling a story in oral language.	Give voice commands to operate a device

Figure 1 shows an actionfunction diagram of a bathtub where the dashed boxes represent user activities and solid boxes represent the related product functions contained within each activity. The arrows represent the flow of energy or material similar to a functional model. Figure 1 is for illustration purposes only and the detailed procedure to build an actionfunction diagram follows.

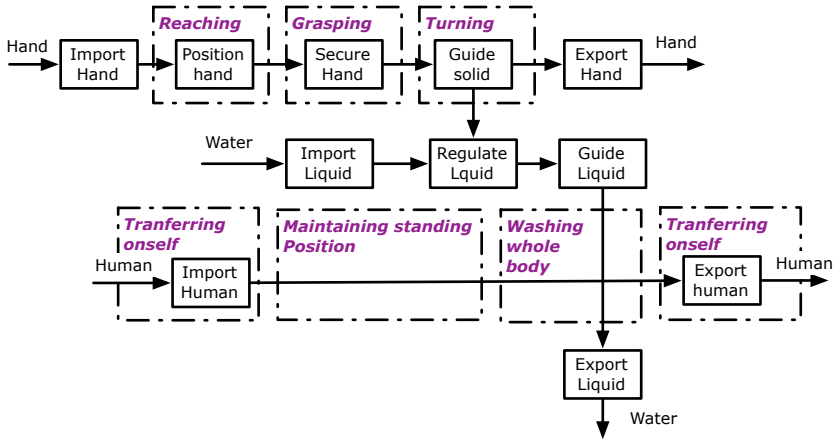

Figure 1. An illustration of an actionfunction diagram for a bathtub. Dashed boxes represent user activities with related product functions contained within each activity.

Figure 2 shows the steps in creating an actionfunction diagram: problem definition, activity modeling, functional modeling, building actionfunction diagram, and checklist for actionfunction diagram. This process is explained with the example of a can opener.

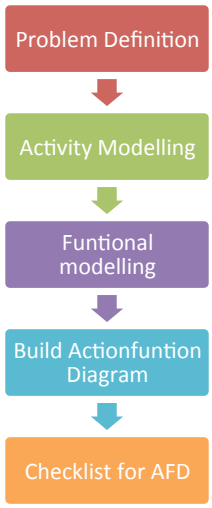

Figure 2. Method to create and actionfunction diagram of a product.

Step 1: Problem definition

The problem definition step signifies "knowing what you are designing" before starting with the process. This step is similar to the preliminary design task found in any of the textbooks on product design. Otto and Wood describes this step as formulating a mission statement [1]. The elements of the problem definition those are crucial for actionfunction diagram are emphasized here.

- Gather and list all the customer needs
- Decide the scope of design and set the system boundaries
- Define the overall functionality of the product

As an example we will proceed to create an actionfunction diagram of a pre-existing product, a manually operated can opener as shown in Figure 3. The example will help to illustrate step 2, step 3, and step 4.

Figure 3. Manually operated can opener

Step 2: Activity Modeling

When creating an activity diagram, list all the activities that are performed or can be potentially performed while using the product. List only the high level activities and not the detailed activities at this stage. Posing a question like, "What are the basic steps the user needs to perform to complete the task using the product?" can help with the activity modeling. Ensure that all customer needs are taken into consideration while listing the activities. Also, clarify the scope of design at this stage.

Once all the activities are listed, arrange all the activities in parallel and sequential manner and connect the activities with arrows to form a network. The direction of arrows indicates the precedence of one activity with respect to the other activities. The example of an activity diagram for the can opener follows. Figure 4 shows the activity diagram of a can opener. Note that in the activity diagram, the overall activities, represented using natural language, are denoted

in blue boxes with formal ICF activities and the associated alphanumeric code contained within black dashed boxes.

While opening a can with an opener, the user carries the unopened can and places it on the work surface. Next, the user picks up the opener and engages it with the can. After engaging the opener with the can, the user twists the handle with one hand while holding the opener with the other. Finally, the user removes the lid.

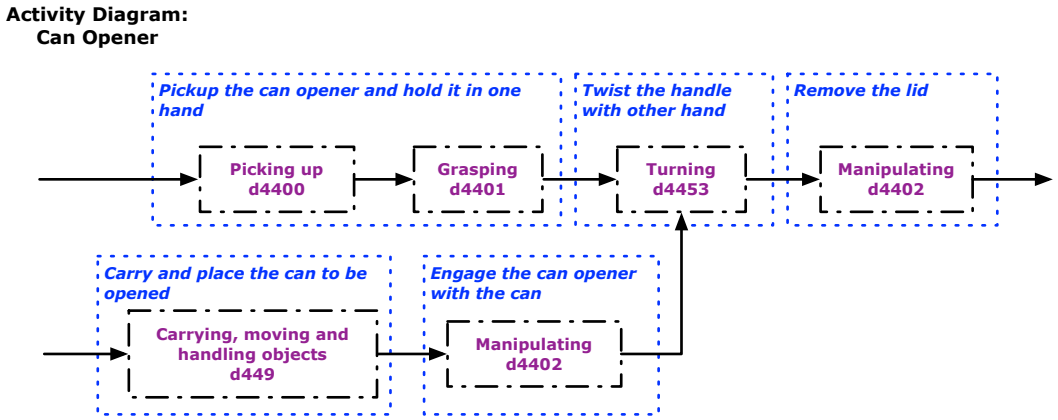

Figure 4. Activity diagram of a can opener

Step 3: Functional Modeling

To develop a functional model, first list all the product functions that are required to achieve the overall functionality of the product. Otto and Wood recommend developing an activity diagram as a prior phase of function structure development, specifically for formulating sub-functions through task listing [1]. Also, mapping the product functions to the customer needs is helpful for functional modeling. Next, describe all products functions using functional basis. Refer to Otto and Wood for the guidelines on function structures and the Functional Basis [1]. Place the functions in parallel and sequential manner based on the flows of material, energy and signal. A functional model acts as the basic layout for building actionfunction diagram.

Figure 6 shows the functional model of a can opener. The can opener imports and positions a user hand. The handle of the opener provides the function of positioning hand. The product also has a provision for coupling the can to the opener. Further, the handle transfers human energy to rotate the gear. The set of gears convert the human energy into rotational energy, which is

expended to guide the can relative to the opener and rotate the cutter. The rotary cutter performs the cutting action, and separates the lid from the can.

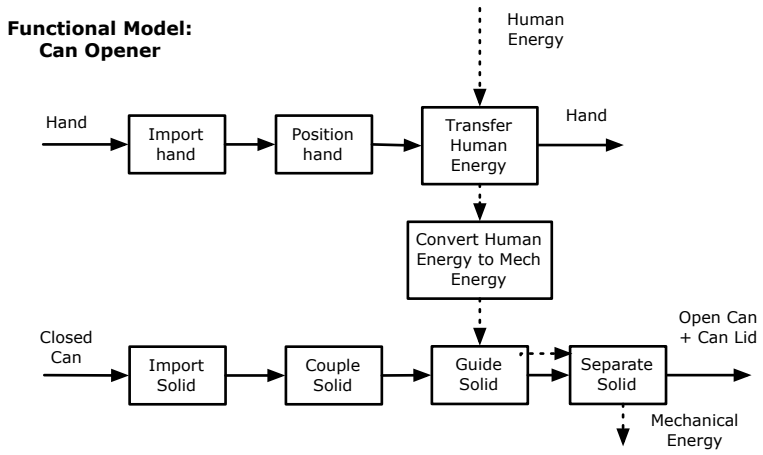

Figure 5. Functional Model of a can opener

Step 4: Build the actionfunction diagram

An actionfunction diagram is created by merging the activity diagram with the corresponding functional model. The relevant user activities are superimposed on corresponding product functions within the functional model. For instance, when the user is turning the handle of the opener, the product is transferring human energy and converting it to mechanical energy. The mechanical energy is used to rotate the cutter and cut through the lid. The lid is not exported by the system but removed by the user manually. Figure 6 shows the actionfunction diagram of a can opener.

Some activities may not have functions associated with them. For example, the activity of manipulation, to remove the lid away from the can, does not have any product function associated with it. Similarly, some functions may not have any activities associated with them. For example, the guide solid function performed by the set of gears is independent of the user. Such functions are referred as the internal functions of the product.

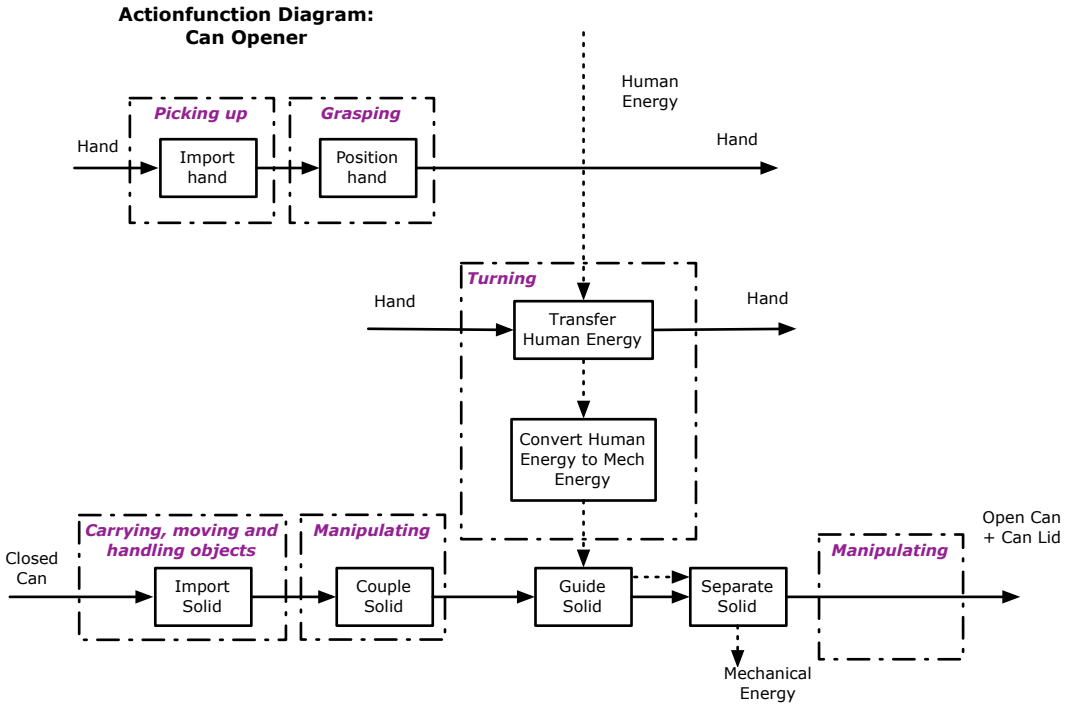

Figure 6. Actionfunction diagram of a can opener

Step 5: Checklist for actionfunction diagram

It is recommended to go through the checklist after creating an actionfunction diagram as a check for completeness and correctness. The checklist also acts as a guide for creating actionfunction diagram. However, it is advisable to first create actionfunction diagram following the procedure and then use the checklist.

- Is the overall functionality of the product achieved?
  - Check the problem definition of the product
- Are all the customer needs considered?
  - Check the elementary list of user activities, created in step 1, to see if all activities are included
- Are the laws of conservation maintained?
  - Energy and material that goes into the system must also go out of the system
- Are the system boundaries clearly defined?
  - Verify the scope of design established before starting with the design
- Are the sequential and parallel functions and activities correctly placed?

- If one can re-arrange the activities and functions in more than one technically correct way, choose the arrangement that is most appropriate

- Are all the energy flows considered?
  - Check if all forms of energies are included, specifically human energy

- Are any signals going into and out of the system?
  - Include all necessary signals, especially signal input from the user and signal output to the user

- Are the arrows specifying energy, material and signal distinct and clearly marked?
  - Specify the legend if its different form the conventions used for functional modeling

- Are all functions described using functional basis?
  - Refer to Otto and Wood for Functional Basis definitions and classification

- Are all the activities expressed using the ICF?
  - Refer to ICF browser <http://apps.who.int/classifications/icfbrowser/>

- Are the activities and functions abstract?
  - Use non-specific terms for describing activities and functions to maintain generality of the design and its application

- Can any of the activities and functions be removed without affecting the overall functional requirements?
  - Remove all the redundant functions and activities

- Are the activities and functions atomic?
  - If the function or activities can be divided into two or more, then divide it to the lowest level possible

Caveats of actionfunction diagram

This section describes some caveats of actionfunction diagram modeling. They provide helpful guidelines for creating consistent user-product interaction models.

- Include "export" function only if the product intentionally sends material or energy out of the system boundary.
  - *Example:* Popcorn is exported out of a popcorn maker but the heat generated due to friction is not exported by the system.

- Use the function "secure hand" only when a specific component of the product get attached to user hand.

- *Example*: A circular loop around the handle that prevents the product or a part of the product from slipping out of the hand is modeled as a function "secure hand".

- When the user's hand is repositioned to perform another set of tasks, the activity of "reaching" is repeated.
  - *Example:* The user has to reach out to open the door of a washer and again reach out to press the start button.

- The ICF user activity of "maintaining body position" is used to model a sitting or standing posture of the user. This activity is important for modeling, especially, when the system boundary includes the space around the product.
  - *Example:* While designing the large household appliances the location and position of the appliance in the house is an important consideration for user-centric design.

- "Grasping" is not required when the activity can be performed with a closed fist.
  - *Example*: A round doorknob needs "grasping" and "turning", while lever type knob allows "pushing" with a closed fist.

- The activity of "picking up" signifies that the user picks up the product itself. Weight of the product that does not require "picking up" activity is not critical for the design.
  - *Example:* Plier type stapler needs to be lifted up before using as compared to the desk stapler that need not be picked up.

- The activity of "carrying, moving and handling objects" represents that the object to be operated upon is imported within the system boundary.
  - *Example:* The user carries the can to be opened or the paper to be punched into the system boundaries.

- The touch type or press type buttons should be modeled differently.
  - *Example:* The touch type buttons are modeled as a function "actuate signal" and the related user activity is "reaching". On the contrary, for push buttons are modeled as the activity "pushing with fingers" while the product "guides solid" to actuates the signal. Also note that, the human energy is not required for touch type buttons but is required for push type buttons.

- Residual energy though important for conservation of energy, does not affect the user-centric design.
  - *Example*: The vibration and noise generated by the electric knife can be neglected in the actionfunction diagram.

- Importing human energy function is not required; it is assumed that human energy is used to perform the activities. Explicitly state conversion of human energy into some other form of energy when significant amount of human energy is required.
    - *Example:* Human energy is not required to operate touch buttons but is required to crank an engine.

- Tracking of human or human parts is significantly important for user centric design. To be precise, 'Human' and 'Hand' are used specifically. 'Human' is used if the entire human is involved in the activity. When the user performs a task with upper limb or hand, it is represented as 'hand'.
    - *Example:* Model as "human" for activities like entering or exiting a bathtub and model as "hand" for the activities like operating a switch.

Application of actionfunction diagram for universal design

The actionfunction diagram is used as a product representation framework to design universal products [9-13]. Actionfunction diagrams are created for a typical and a universal product and the two products are functionally compared to observe the design similarities and differences. These observations are then studied to create heuristics for universal design. Since universal design of products is highly focused on the user, the actionfunction diagram acts as effective tool to model the disability in relation to the user environment.

In addition, the actionfunction diagram helps to identify the internal functions of the device that are essential to perform the overall function but may not contribute towards improving the user experience [9]. Thus, the designer can identify the product functions that have direct impact on the user-centric design.

Summary

The paper explains the procedure to create actionfunction diagrams for user centric design of products. Some of the advantages of actionfunction diagrams are focusing closely on product and user interaction, highlighting those functions of a product in which the user is involved, and allowing for analysis of user-product interaction in the early design stages.

This method can be introduced in an engineering design curriculum for user-focused design. The aim of this paper is to educate the design community and engineering educators about the importance of user modeling and the available methods to practice it. In addition, this manuscript

documents the up-to-date information on the actionfunction diagram, which can be further used by product designers or researchers for creating better methods.

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