INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

AFFORDANCE FEATURE REASONING: A CASE STUDY FOR HUMAN-PRODUCST INTERACTION

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ABSTRACT
Affordances of a product are messages which could be perceived by a human user so that the product function can work by a user's activities naturally induced with the help of such messages. Affordance features are structural elements providing affordances. That is, affordance features and their relations as well as human users are critical constituents for affordance. In this research, we introduce three types of affordance features as *Functional Affordance Feature (FAF)* related to the physical properties for behaviors of an object by physical laws, *Ergonomics Affordance Feature (EAF)* related to convenience for user activities and *Informative Affordance Feature (IAF)* related to the properties that can help human understand the functionalities and so guide him/her to proper operations. Above all, identification of affordances and affordance feature reasoning of a typical household product is conducted through function and user task analysis reflecting user aspects and product function aspects. Some critical affordances and affordance features are identified through geometric and function reasoning.

Keywords: Affordances, Affordance Features, Human-Product Interaction

1 INTRODUCTION

1.1 Background
Affordances of a product are considered as the properties of the product inducing human activities for operating the product [1][2]. Interactions between human and a product are made through specific features of the product, which are adequate to the given task context. During human interactivities with the product, perceived features of the product vary according to the context given to human. For example, grasping features are critical in grasping and manipulation features, at control. Features can be implicated as engineering significant aspects of the geometry of a part or assembly and thus plays a very import role in product design, product definition and also reasoning for various applications [3][4]. That is, feature concept earlier used in design and manufacturing satisfies the structural aspect for product and space as needed to provide affordances. So affordances need to be considered in the level of features.

1.2 Research on Affordances
On affordances for complex activities, Gaver introduced two concepts of affordance such as sequential affordances and nested affordances. Sequential affordance is about situations in which one activity on an affordance leads to new affordances over time, while nested affordance is concerned with grouping affordance in space [5].
Brown and Blessing addressed the relationship between function and affordance. In mode of deployment of their research, structural relations between an object and human user are operational relations for having the object behave, which behaviors finally result in the function of the object. The mode of deployment is about how to use the object for achieving the function and thus human actions (operational relations) induced by the object can be the causal relations for the function [6].

Maier and Fadel proposed the Affordance-Based Design (ABD) methodology in the field of engineering design, and affordances are categorized into positive affordances and negative affordances as well as artifact-artifact affordance and artifact-user affordance [7][8]. Maier *et al.* introduced

Affordance-Structure-Matrix (ASM) for evaluating what affordances are embedded in each component of a product and thus grading. This matrix can illustrate correlations of affordances and also of components [9].

Galvao and Sato proposed Function-Task Interaction (FTI) Method. This method includes a general product development process and additionally affordance method, especially FTI matrix [10][11]. In the FTI method, product functions and user tasks were derived from function decomposition and task analysis and then linked to each other in the FTI matrix. Kim *et al.* identified affordances for interior space such as a conference room using Function-Task Interaction method, where affordances for social issues have been addressed beyond function oriented affordances [12].

Still and Dark conducted a research on distinguishing effects of affordances from those of conventions by experiment of directional button pressing task responding to directional cues as up-down or right-left. The result of their research shows that human tends to conduct actions induced by such as spatial mapping like affordances rather than convention but did not get the evident differences of effect between them [13].

1.3 Research on Affordance Features

Murakami *et al.* tried formulation of affordance feature for product design by experiment with some simple shaped (elliptical-, conical- or rectangular-section) objects which are considered as the control devices. In their research, it was shown that existence of strong relation between some geometric attributes such as height, aspect ratio between width and length are strongly associated with human activities such as pushing, pulling, turning and tilting [14].

Kim *et al.* provided affordance-feature map obtained from user task observation in a public space as a lobby. The map illustrates inter-relationships of affordances in various levels as well as those of features in hierarchical structure from area level, to set level, to object level features [15].

In this paper, we introduced three kinds of affordance feature classes in our previous research on hand-held devices [16] and illustrate some critical affordances from a typical household product as a toaster and their associated affordance features.

2 AFFORDANCE FEATURE CLASSIFICATION

Our affordance feature classifications are *functional, ergonomics and informative affordance features* as follow:

- **Functional Affordance Feature (FAF)**: related to the physical properties for behaviors of an object by physical laws.
- **Ergonomics Affordance Feature (EAF)**: related to convenience for user activities.
- **Informative Affordance Feature (IAF)**: related to the properties that can help human understand the functionalities and so guide him/her to proper operations.

Some examples of our affordance features in each class of FAF, EAF and IAF are shown in figure 1 and figure 2 respectively. Because the role of distance between rotating axis and arm axis is strongly related to the Moment Law as a physical effect, in which the Moment (or Torque, TQ) equals to the vector product of moment arm and force applied, the distance could be classified in FAF.

On the other hand, containment of the trigger in grasping area could be an EAF, for human grasping activity naturally induces depressing activity for getting more rotating force as well as simultaneously and stably maintaining the product with more grasping force as shown in figure 1. Where grasping area is a region contained in a human hand while grasping.

One critical informative affordance feature in hand-held devices is shown in figure 2. The triangle of the upward-motion button points in the correct (upward) direction when the device is held as afforded so that this coincides with the upward motion of the screen. To lower the screen, the downward button is pressed, as afforded by the triangle pointing downward. We organize these features into the affordance features as coincidence of configuration and behavior of the target object while grasping.

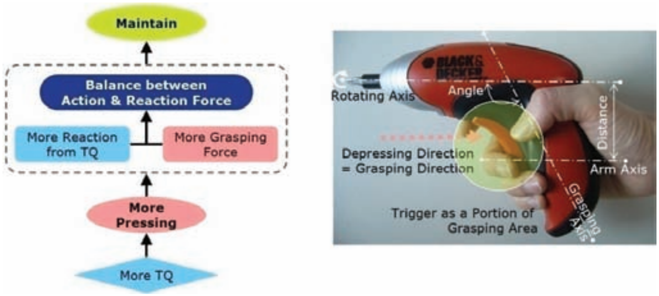


Figure 1. Examples of functional & ergonomics affordance features in a power screwdriver

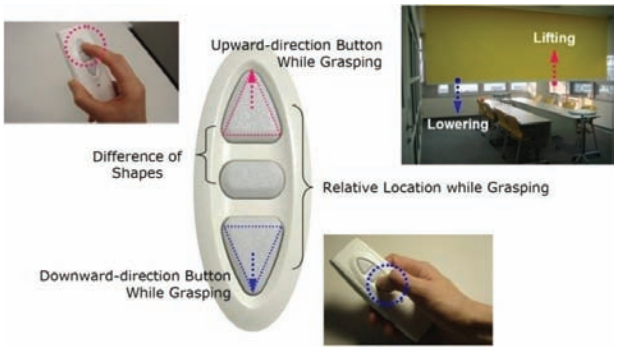
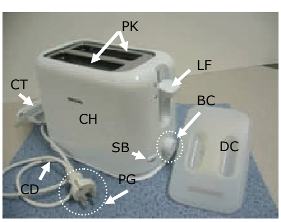


Figure 2. Examples of informative affordance features in a remote controller

3 AFFORDANCE FEATURES OF A TOASTER

3.1 Overview of User Observation Experiment for a Toaster

We selected a toaster of a kitchen appliance for the case study based on following criteria: 1) commonly used in everyday life, 2) movable, 3) multiple parts interacted with human according to task context and 4) variety of age range or experience level groups. The parts of the toaster used are shown in figure 3(a) and the test environment is shown in figure 3(b). Two fixed video cameras (2nd video camera not shown in figure 3(b)) and one hand-carry video camera are used for recording detail human activities to be analyzed as well as a kitchen-like snapshot is projected onto a wall in front of the test person for empathic context of working in kitchen. Four of them were observed in the organized test environment shown in figure 3(b) and the others were done in a real kitchen environment. The age range of the test persons is from 20s to 70s. One of them has no experience of a toaster and another test person uses it about two times per week. The others (5 test persons) have experience from 5 to 10 times through their life.



PK:	Pockets
LF:	Lifter
BC:	Browning Control
SB:	Stop Button
PG:	Plug
CD:	Cord
DC:	Dust Cover
CT:	Crust Tray
CH:	Chassis

(a) (b)

Figure 3. (a) Parts of a toaster and (b) test environment for user task analysis

3.2 Function Decomposition and User Task Analysis

Overall function of a toaster can be defined as '*toast bread'*. From decomposition of the overall function, sub-function chains, which are for slices of bread, electricity and thermal energy as main flows respectively, are obtained as shown in figure 4. For flow of slice of bread, sub-function chain composed of import, secure, contain, popup and export solid are obtained. Opening of the two pockets (PK in figure 3(a)) are for import and export sub-functions, and depressed volume of each pocket is for secure and contain sub-functions. For flows of electricity and thermal energy, sub-function chain consisting of import, transmit and actuate electricity (EE), convert EE to thermal energy (TE), transmit TE. Also, protect solid (by a Dust Cover, DC) and sense TE or Time (as a Browning Control, BC) well as stop TE (by a Stop Button, SB) are obtained as auxiliary sub-function chains.

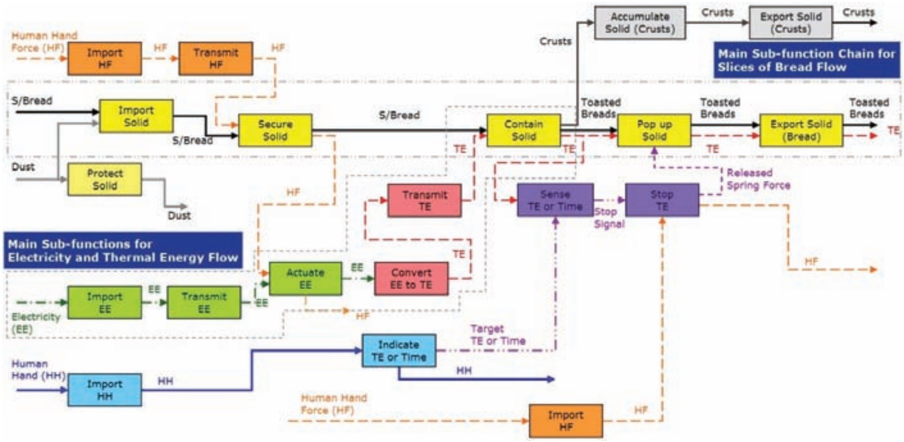


Figure 4. Functional model of a toaster

The test persons are initially given five tasks as 'prepare toaster', 'connect electricity', 'toast slices of bread & eat', 'clean toaster' and 'return toaster'. But 'toast slices of bread & eat' task is refined into 'toast slices of bread' and 'serve toast' as a result of experiment. The reasons of this refinement are that no interaction is done between users and toaster during eating and 'serve toast' follows 'toast slices of bread' with enough time as shown in table 1. The only sub-tasks of toast slices of bread are shown as 'open toaster,' 'insert slices of bread,' 'fix slices of bread & turn on,' 'select browning level' and 'turn off manually' which is optional in table 1.

Table 1. Tasks and sub-tasks for toasting (only critical sub-tasks are shown)

Task	Sub-task
Prepare toaster	
Connect electricity	Wind off cord
	Plug in
Toast slices of bread	Open toaster
	Insert slices of bread
	Fix slices of bread & turn on
	Select browning level
	Turn off manually
Serve toaster	Pull out toast
	Place toast on dish
Clean toaster	
Return toaster	

3.3 Interactions between Sub-functions and User Sub-tasks

We borrowed the function-task interaction matrix method which was originally proposed by Galvao and Sato[10] and linked the test persons' sub-tasks ansd the sub-functions of the toaster as shown in figure 5. Only main flows associated sub-tasks are represented in this function-task interaction matrix. As Galvao and Sato did, we distinguished interactions into three types of interactions as physical interaction (denoted by solid square), cognitive interaction (denoted by empty diamond) as well as both physical and cognitive interaction (denoted in empty star). Most of physical interactions are mapped with import hand, import hand force and transmit hand force as shown in figure 5. During inserting slices of bread into pockets of the toaster, fingers interact with the openings of pockets, thus physical interaction between 'insert slices of bread' task and 'import slices of bread' sub-function is mapped. On both physical and cognitive interactions, the test persons could cognizes degree of containment during inserting slices of bread, fixing slices of bread as well as pulling out toast. And also during selecting browning level, they adjust browning level with hand (specifically fingers) by aligning indicator in BC and scale of chassis (CH in figure 3(a)).

Task & Sub-task / Sub-function	Connect Electricity	Toast Slices of Bread					Serve Toasts
	Plug In	Open Toaster	Insert Slices of Bread	Fix S/Bread & Turn On	Select Browning Level	Turn Off Manually	Pull Out Toast
Protect Dust		◇					
Import S/Bread			■				
Secure S/Bread				☆			
Contain S/Bread			☆	☆			
Pop Up Toast						☆	☆
Export Toast						☆	☆
Import Electricity	◇			◇			
Transmit Electricity	◇			◇			
Actuate EE				◇			
Convert EE to TE				◇			
Transmit TE				◇			
Indicate TE					☆		
Sense TE					◇		
Stop TE						◇	
Import Hand	■	■		■	■	■	■
Import HF				■		■	■
Transmit HF				■		■	

Physical Interaction	■
Cognitive Interaction	◇
Both P/C Interaction	☆

Figure 5. Partial FTI-Matrix on relationship between sub-functions & sub-tasks

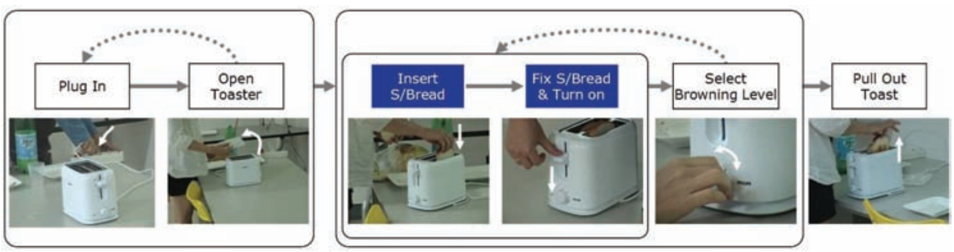
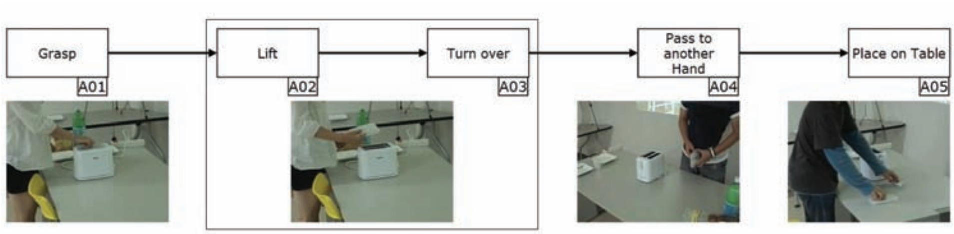
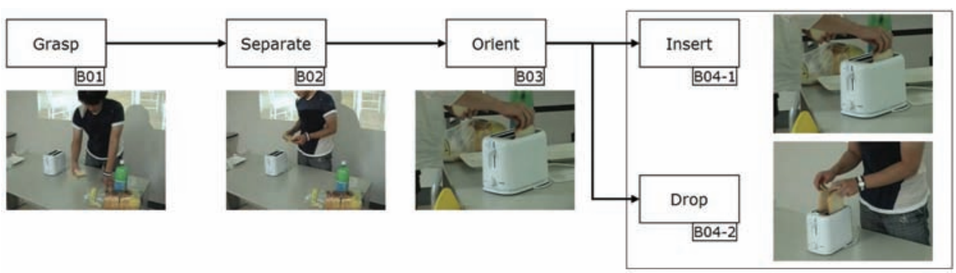


Figure 6. Tasks sequence observed in case study

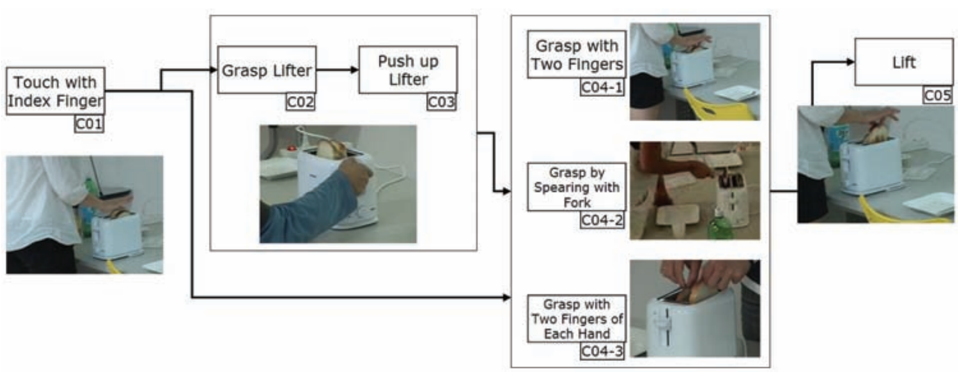
It is shown that various task sequences for using a toaster in figure 6. Each arrow means the order of user activities observed in our case study. Although, the test persons were told that there are no sequential constraints for tasks, all of them conducted 'insert slices of bread' followed by depressing activity for ‘fix slices of bread & turn on’ while there were diverse sequences between ‘plug in’ and ‘open toaster’ as well as between ‘insert slices of bread’ followed by ‘fix slices of bread & turn on’ and ‘select browning level’, respectively. It is remarkable that this toaster has functionality such that securing slices of bread is not activated without electricity input even if slices of bread are in the pockets. The test persons’ detail activities are shown in figure 7. The test persons conduct ‘grasp dust cover (A01)’, ‘lift (A02)’, ‘turn over (A03)’, ‘pass to another hand (A04)’ and finally ‘place on table (A05) for sub-task ‘open toaster’. They conduct ‘grasp slices of bread with one hand (B01)’, ‘separate (B02)’, ‘orient toward opening direction (B03)’, and then ‘insert into/ drop onto pocket (B04-1, 2)’ as detail activities for ‘insert slices of bread’. It can be found in figure 6 that ‘grasp a lifter’ followed by ‘depress in downward direction’ to reach the end of narrow slot is conducted after finish inserting slices of bread. When the desired browning level is achieved, the toasted breads pop up to allow the test persons to ‘grasp (C04-1, 2, 3)’ and ‘lift (C05)’ them. One test person tried to check by ‘touch top of the toasted bread (C01)’ whether it is warm enough to grasp. It is notable that only two test persons tried to ‘push up the lifter (C03)’ for pulling out in contrast to that none of the test persons skipped depressing the lifter for ‘fix slices of bread & turn on’.



(a) Activities for ‘Open Toaster’



(b) Activities for ‘Insert Slices of Bread’



(c) Activities for ‘Pull out Toast’

Figure 7. Detail activities for each sub-task

3.4 Affordances and Affordance Features

From the detail activities as well as the relations between sub-functions and sub-tasks shown in figure 5, we can identify some affordances as follow;

- **Grasp-ability**: On hand grasp as a pre-activity to additional control such as lift, orient or finger activities. This affordance is identified from activities as ‘grasp (A01)’ of ‘open toaster’ sub-task and has relationship with sub-function ‘protect dust’ and ‘import hand’ of dust cover in this toaster example
- **Handcontrol-ability**: On general hand control following grasp activity. This is identified from activities ‘lift (A02)’, ‘turn over (A03)’, ‘pass to another hand (A04)’, ‘place on table (A05)’ of ‘open toaster’ and has interactions with sub-function through dust cover (DC) part.
- **Orient-ability**: A special kind of handcontrol-ability with an intention of repositioning an object by considering the directional properties of the object. From ‘orient (B03)’ activity between separate (B02)’ following ‘grasp (B01)’ and ‘insert (B04-1)’ or ‘drop (B04-2)’, this affordance is identified.
- **Insert-ability**: On human activities to have one object to be contained in another object. It should be considered relations of multiple objects for this affordance. We can identify this from ‘insert (A09) slices of bread into pockets’ activity after ‘orient (B03)’.
- **Drop-ability**: On human activities as releasing an object from state being contained in hand or grasped, so the object could fall and reach his/her intended place. These insert-ability and drop-ability are related to sub-functions of ‘import slices of bread’ and ‘contain slices of bread’.
- **Depress-ability**: On activities of hands’ or fingers’ pressing an object. This is identified from ‘depress lifter’ of ‘fix slices of bread & turn on’ sub-task. In this toaster example, most of sub-functions are related to this sub-task and activity.
- **Lower-ability**: On more inserting or positioning activity, this is also identified from ‘depress lifter’ of ‘fix slices of bread & turn’ sub-task. But this affordance should be considered with the relation between a control device such as lifter of the toaster and a target object such as slices of bread.
- **Touch-ability**: On activities related hand tactile cognition, this is identified from ‘touch (C01)’ for checking whether the toasted bread exceeds graspable temperature or not.
- **Pullout-ability**: Affordance opposite to insert-ability. This can be identified from ‘grasp (C04-1, 2, 3) and ‘lift (C05)’ activities. ‘pop up toast’ and ‘export toast’ sub-functions interact with these activities.

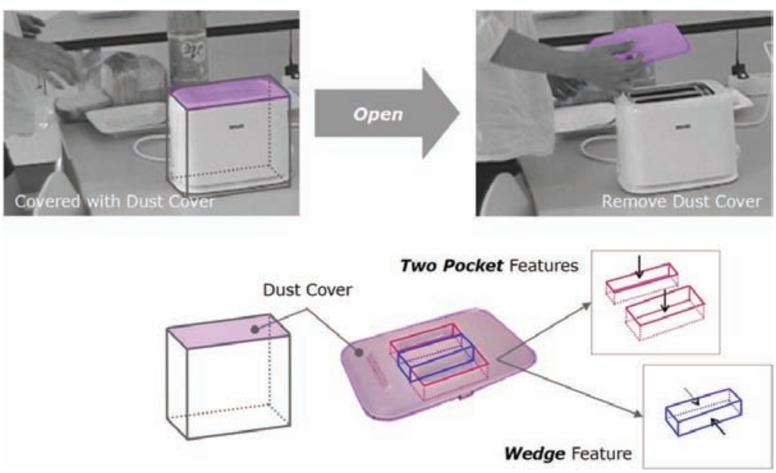


Figure 8. Affordance features for grasp-ability

We now describe the structural elements of the toaster, affordance feature, associated with the affordances identified. Affordance features for grasp-ability and handling-ability are shown in figure 8. Human with intention of toasting, will try to find pockets for slices of bread positioned. And he/she needs pre-task of open toast in case of the toaster is closed. In this context, two parallel pocket features of the dust cover will provide fingers' unique downward accessible direction and subsequently one wedge feature as a handle [4] induces finger's grasping as shown in figure 8. Thus these two features are affordance features for grasp-ability and dust cover's separation from chassis, and its overall size and weight are affordance features for handling-ability. According to our affordance feature classification, these features can be classified into ergonomics affordance features except for separation in functional affordance features. Affordance features for orient-ability, insert-ability and drop-ability are shown in figure 9. Human can conduct hand control of slices of bread because their size and weight affording it. In particular, the thickness of slice of bread induces hand grasp as well as its directions in wide and arbitrary flat surface could provided clues for orienting while grasping. Each pocket of the toaster has very similar shape and opening which provide only one accessible direction. So these can be affordance features of orient-ability.

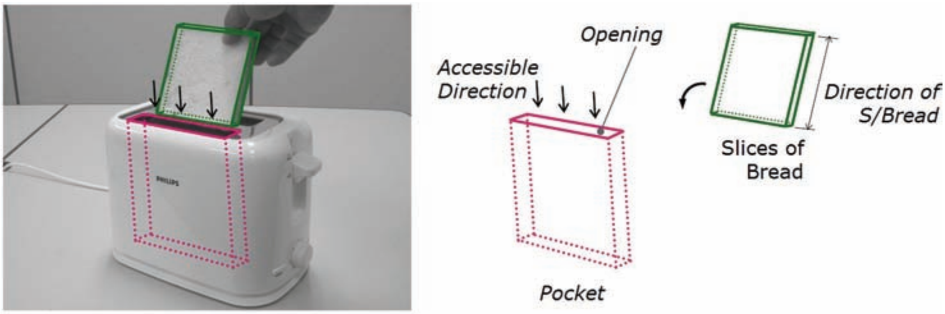


Figure 9. Affordance features for orient-ability, insert-ability and drop-ability

Furthermore, insert-ability has those of orient-ability as well as relation that the sectional sizes of slice of bread along access direction should not exceed those of opening and section of each pocket to some extent of depth. Finally, it is permitted to be contained in the pockets by just dropping due to the features for orient-ability as well as the relation between slices of bread and pockets on drop-ability. Human' depressing activity is induced by the top surface of protrusion, which is the lifter, separated from the chassis in figure 10. Thus these are affordance features for depress-ability.

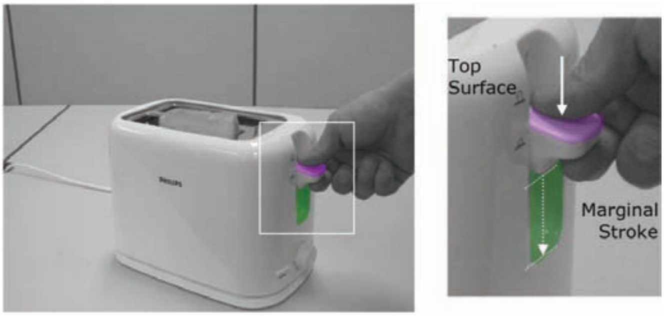


Figure 10. Affordance features for depress-ability

Affordance features for lower-ability of the lifter are shown in figure 11. Those could provide much of information for toasting as follow; when slices of bread are inserted in pocket(s), initial position of the lifter and bread's partial containment in pockets as well as top surface of the lifter can play a role of inducing human depressing activity for full containment. The initial position of the lifter is just below the top of the opening, which affords a human hand to continue a natural downward motion for conducting an additional task or action just after inserting slices of bread. Thus, this downward motion of the hand can depress the lifter to lower them into the pockets. Additionally, downward marginal stroke under lifter also provides a clue for these activities. These affordance features could illustrate why all of test persons conducted 'depress lifter' right after 'insert slices of bread' without intervention of 'select browning level'. From affordance features of lower-ability, it becomes obvious that affordance features and their relations as well as users are very critical for affordances. All of these affordance features are classified into our informative-affordance feature as well as exhibit Gaver's sequential and nested affordances. Affordance features for touch-ability and pullout-ability are shown in figure 12. Partial containment of slices of bread in pocket provides accessing activities as touch, grasp and so on. During toasting, the portion of slices of bread could be slightly extruded from pocket and thus is small rather than those after pop up, thus this partial containment affects the degree of inducing those human touching activities. With the same affordance features of insert-ability and partial containment, the user's pulling out activity could be induced. The degree of partial containment could be in our ergonomics affordance features because convenience of touching and grasping is affected by it.

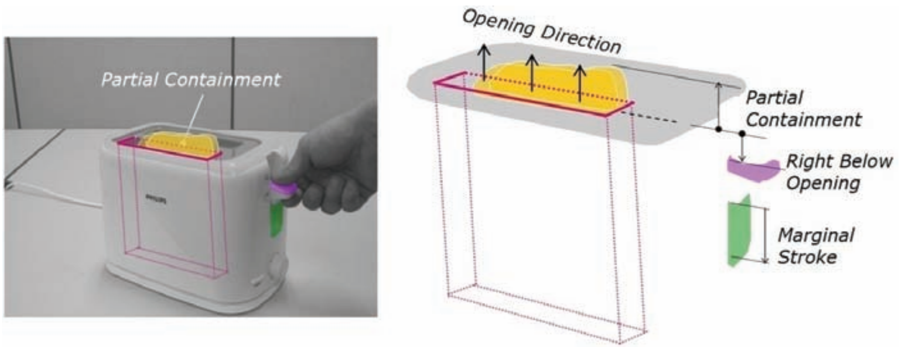


Figure 11. Affordance features for lower-ability

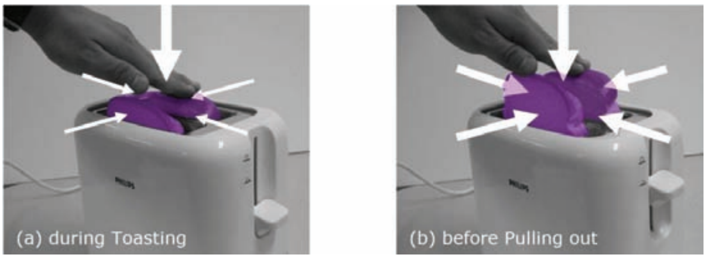


Figure 12. Affordance features for touch-ability and pullout-ability
(Size of each arrow means arbitrarily relative degree of accessibility to each other)

4 CONCLUSION

In this research, affordances and affordance features of a typical household product as a toaster are identified through geometric and function reasoning. From detail activities of those tasks and the sub-function, we identified affordances such as grasp-ability, handcontrol-ability, orient-ability, insert-ability, drop-ability, depress-ability, lower-ability, touch-ability and pullout-ability. Most of the affordances are between human user and an object but insert-ability, lower-ability and pullout-ability should be considered among human as a user and multiple objects (one as a control device and the other as a target object) with relations between them. Affordance features for grasp-ability of the dust cover are two parallel pockets and their consequent wedge feature as a handle. These features guide fingers' accessing direction and thus grasping direction. Size and weight of the dust cover are affordance features for handcontrol-ability as lifting and directional properties are affordance features for orient-ability and also for insert-ability as in the relation between pockets and slices of bread. For lower-ability of the lifter, its initial position right below the top of the opening and marginal stroke in same direction of motion of bread are affordance features with valid relation of partial containment between pockets and slices of bread. The partial containment is also associated with touch-ability and pullout-ability. Among affordance features identified in this study, we classified size and weight of the object into ergonomics affordance features, separation of dust cover and lifter from chassis into functional affordance features. Finally the initial position of the lifter is our informative affordance features. In conclusion, it is remarkable that affordance features and their proper relations as well as human users are very critical constituents for affordances.

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