Title:
Accessibility Analysis of Tools in Product Module Interface Operations

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Introduction:

Product personalization and market globalization require product meeting different needs of users. Open-architecture product (OAP) is proposed using adaptable interfaces and different functional modules to achieve the product adaptability, extendibility and sustainability [5]. The functional modules in the OAP include common platform modules, customized modules and personalized modules. These three types of modules are connected using adaptable interfaces to form an OAP. Adaptable interfaces are used to connect functional modules to ensure that personalized requirements are satisfied through upgrading or replacing of functional modules. The interface affects the operation of functional modules in replacement, which impacts the product adaptability. Operation efficiency of product interfaces is also important for third parties to develop personalized modules for different users. It is therefore important for interfaces to connect modules with the operation efficiency in the module assembly and disassembly [4].

Based on the functional requirement, a product interface may transfer power, motion or information using different physical structures or formats. Operability of an interface is decided not only by its function property, but also its attended mode and operation space. In order to transform product specifications into component configurations based on required product functions, interfaces integrate product modules with a structure mapped from product functional requirements to physical components [1]. Interfaces are essential for the development and applications of an OAP. Varieties of interface attributes cause complicated operations in the assembly and disassembly of modules [3]. The interface classification, operational space and tools are important elements for the interface accessibility, which has switched research focuses from the modular design into feasibility analysis of interfaces. It is essential for the tool operability and accessibility of interfaces in assembly and disassembly of the module. It is therefore necessary to look at relations between interfaces and constraints of modules and interfaces to ensure the adaptability of the interfaces. Considering the lack of research on the interface accessibility, product interfaces are analyzed in this paper to evaluate OAP interfaces and tool operations. The proposed method combines a box-based method and the global accessibility cone with depth (GAC^d) to analyze the tool accessibility for interface operations. This research also presents an approach to class and code interfaces in order to manage interfaces for the accessibility of operation tools.

Main Sections:

Classification and coding of interfaces

Research objects in this paper are mechanical interfaces. An interface is defined as a connector linking product modules. Codes are proposed for the interface classification based on linked module types, technique specifications, relationships of connections and connection forms. A code is a string of

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characters describing an interface. Similarities and differences of interfaces can be distinguished by the code characters. The code of an interface is defined with nine characters including two modules connected by the interface, the assembly relationship, connector, technique specification, module types, connection structure, connection form, and additions of the interface.

Tools for interface operations

Tools are used for the operation, connection, measurement and modification of interfaces. Tools include manual and power tools; pneumatic, hydraulic and electrical tools, etc. Tools specifications are based on manuals of hardware tools and website sources [2, 6],

Box-based methods

A bounding box can be a bounding sphere, axis-aligned bounding box (AABB), oriented bounding box (OBB) or a fixed direction hull (K-dops) that provides an envelope surrounding the geometry features of a part to test the collision in a complex product operation environment. AABB is the smallest six-sided enveloping of a part based on its coordinate axis. Sides and surfaces are parallel or perpendicular to the axis. OBB is a surrounding box of geometry features of a part in a direction to achieve the smallest hexahedron. In the complex operation environment, OBB and K-dops are complex in calculation [20]. AABB is used to represent tools in this research for the accessibility analysis.

Global accessibility cone with depth (GAC^d)

The GAC^d consists of 180×360 pixels with total 64800 directions on a discrete unit sphere. The number of pixels is exactly matched with 180 colatitude angles (φ) and 360 longitude angles (θ) in a spherical coordinate. There is a one-to-one mapping relation between directions in the GAC^d and unit vectors in a 3D space, which are defined by angles φ_s and θ_s. φ and θ are used to calculate unit vectors and to represent operation directions using an equivalent pixel (φ, θ)[3].

Feasibility analysis of interfaces

The tool analyzed in this research is composed of four parts: a head that interacts with interface, an effective handle that contacts with operator, a cervix linked to the head and handle, and an extension handle. Each part of a tool is an independent unit to analyze its accessibility by combining the bounding box and GAC^d. Based on the definition shown in Fig. 1, Sixteen geometric parameters are used to represent an operational tool, they are α, β, α_{min}, α_{max}, r_e, h_e, a_a, b_a, c_a, b_c, c_c, a_x, b_x, c_x, d_f, and L.

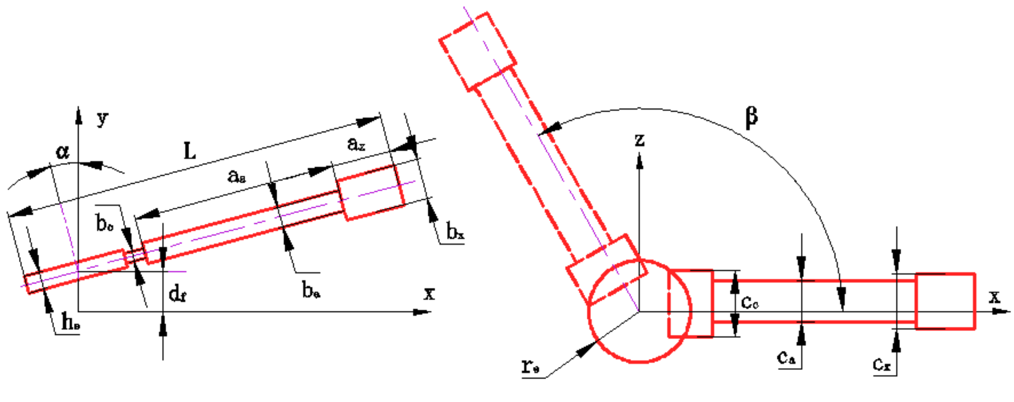

Fig. 1: Parameters of a tool: (a). Projection on the x-y plane. (b). Projection on the x-z plane.

Where α is an access angle between y-axis and the rotation axle of the tool ranging from 0° to 180° while β is the tool rotation angle. As shown in Fig. 2, tools are classified into two types based on α: Tool rotation around the fastener axle when α is zero, Tool rotation not around the fastener axle when α is not necessary zero. When α is zero, the tools are classified into two types: the projection of bounding boxes about all parts of the tool onto X-Z plane is symmetrical about the origin, and the projection of bounding boxes about all parts of the tool onto X-Z plane is not symmetrical about the origin.

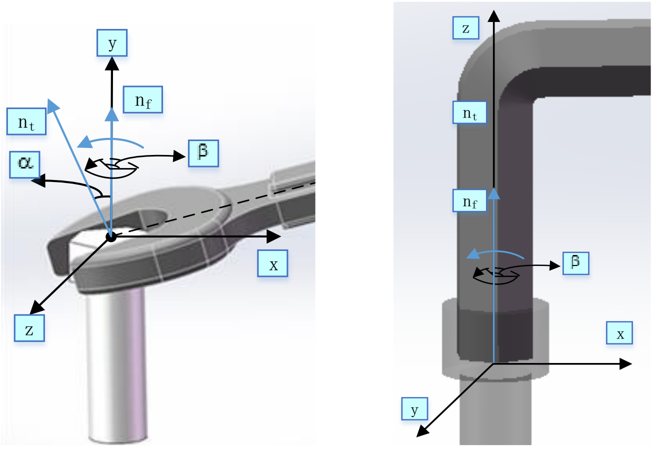

Fig. 2: Classification of tools: (a). Tool rotation not around the fastener axis. (b). Tool rotation around the fastener axis.

An operational tool rotates about y-axis with variations in the access angle α and the fastener removal displacement d_f. In order to analyze its accessibility, a searching range based on these variations is defined along the φ direction at the longitude angle θ. The defined searching range at the angle θ is used for the interference check of the bounding box of the tool with a GAC^d including the depth information. The check is executed until the required minimum tool-rotation angle β_{min} is found within the GAC^d. A searching range for an effective handle at a longitude angle θ is defined via four angles φ_{*1}, φ_{*2}, δ_{*1} and δ_{*1}, where $* = \{e, a, x, c\}$ representing four parts of a tool.

The minimum distance between parts or obstacles around an interface and the center of GAC^d in the working state of an operational tool are used to decide accessibility of the tool by judging if the intersection point between the direction of the pixel (φ, θ) and the tool is outside the area formed by the operating tool from the start position to the tool-rotation angle corresponding position. There are three different criteria examined for three different angle configurations: (a) $\varphi_{*1} < \delta_{*1} \wedge \varphi_{*2} < \delta_{*2}$, (b) $\varphi_{*1} < \delta_{*1} \wedge \varphi_{*2} > \delta_{*2}$, (c) $\varphi_{*1} > \delta_{*1} \wedge \varphi_{*2} > \delta_{*2}$.

φ is found by searching the point in the GAC^d surface that has the minimum distance between parts or obstacles around an interface and center of the GAC^d. The minimum distance corresponding direction is represented by pixel $(\varphi_{min}, \theta_{min})$. For example, the following criterion is used to examine the feasibility $(\Re)$ of the configuration (a).

$$\Re = \begin{cases} 1 & r^{\varphi_{*1}}(\varphi) \le R(\varphi,\theta) \vee r^{\varphi_{*2}}(\varphi) \ge R(\varphi,\theta) \\ 0 & \delta_{*1} \le \varphi \le \varphi_{*1} \end{cases}$$

$$r^{\varphi_{*1}}(\varphi)=\frac{L\sin(\alpha-\varphi_{*1})}{\sin(\alpha-\varphi)};\quad r^{\varphi_{*2}}(\varphi)=\frac{L\sin(\alpha-\varphi_{*2})}{\sin(\alpha-\varphi)};$$

$*=\{e,a,x,c\}$ including the head, cervix, handle and extension of a tool in the analysis. The accessibility of the four parts of a tool is analyzed independently based on the access angle α, moving distance of the interface in a GAC^d. The axis-aligned bounding boxes of tool parts are embedded into the proposed method to solve problems such as any irregular shape and the great size difference of the head and handle.

Case Study:

A paper-bag folding machine is used as an example to verify the proposed method in the accessible analysis for the operation of module interfaces [7]. Following the definition and national standards, a single-headed wrench stay, a hexagon wrench and two different specifications of Philips screwdrivers are four tools used in the interface operation of the machine. A common feature of these four tools is that the handle and head are connected directly, i.e. $b_c = c_c = a_x = b_x = 0$.

Due to the space limitation, a hexagon wrench is selected to explain the analysis process for the accessibility of interface I_4. The type and code of the interface, linked modules, and the operation tool of the interface are listed in Tab. 1. The projection of bounding boxes about the hexagon wrench onto the X-Z plane is not symmetrical about the origin, $\alpha=0$. The initial position of the hexagon socket head cap screws becomes the center point of the GAC^d, and the removal direction of the hexagon socket head cap screws is aligned to its y-axis. The GAC^d and initial position of the hexagon wrench are shown in Fig. 3. Tool parameters and calculation results are shown in Tab. 2. Based on the analysis, the minimum application angle β_{min} of the hexagon wrench is $30°$. $\Re=1$, when φ is within $\varphi_{*1},\varphi_{*2},\delta_{*1},\delta_{*2}$. When the tool is at direction pixel ($\varphi_{min}, \theta_{min}$), the $\beta>\beta_{min}$. Therefore, the hexagon wrench is accessible to operate interface I_4.

Conclusions:

Mechanical interfaces support connections and function interactions of modules in an OAP. The interfaces should be operable and feasible to meet the OAP need in upgrading function modules. This paper analyzes the interface accessibility based on interface types, connectors and operation tools. The tools are divided into two types based on the access angle defined during the operation. A GAC^d is combined with a box-based representation to simplify parameters in the complex structure of operation tools to analyze the interface feasibility. The proposed accessibility-tool reasoning method is based on parameterized operational tools and the global accessibility cone with depth that approximates the obstacles of interfaces. It avoids detecting the complex collision for a relative easy analysis method. Further work of this research will consider the interface improvement and the assembly sequence optimization with the interface feasibility including surrounding components, modules interfaces and assembly sequences of modules.

InF	Modules and assembly relationship			Name	Encoding	identity	Corresponding tools	criterion
I_4	G/M_1	←	$G/M_{5\text{-}2}$	Hexagon socket head cap screws	M-S-T-FD-1/2-6	GB 70-85 M8×30	Hexagon wrench	GB/T 5356-2008

Tab. 1: Interface I_4 and operation tool for the module operation.

Classification of tools	Name of tools	L	α	$\beta(°)$	r_e	h_e	a_a	b_a	c_a	d_f	X	Y	Z	R
$\alpha=0$	Hexagon wrech	96.82	0	30	3.41	38	90	6	6.82	30	80.90	158.00	46.71	183.55

$\Delta\theta$	X_1	Y_1	Z_1	R_1	X_2	Y_2	Z_2	R_2	φ_{*1}	$\Delta\varphi$	φ_{*2}	d_*	l_*	σ_{*1}	σ_{*2}
34.18	77.94	158.00	48.41	182.71	83.85	158.00	45.00	184.44	59.86	1.79	61.65	68.00	68.09	87.13	88.12

Tab. 2: Tool parameters and calculation results of the tool.

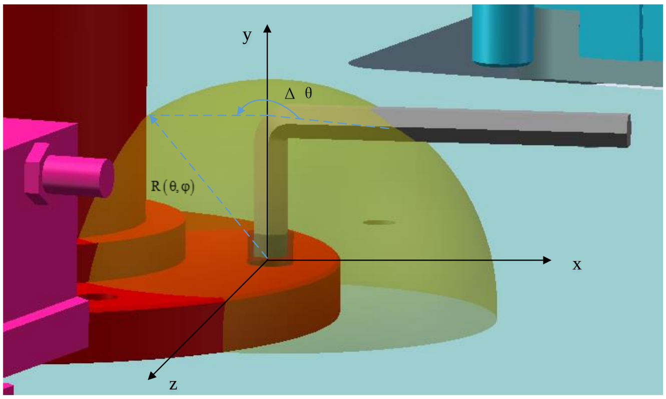

Fig. 3: GAC^d and initial position of the hexagon wrench.

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