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Application of Parametric Sketching and Associability in 3D CAD

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ABSTRACT

The purpose of this research is to make design change automation possible by parametric sketching and design associability in 3D CAD. Applications of the technology in liquid food packaging machinery and its advantages are presented in this paper. For regular shapes such as circles or lines, parameters are used to link dimensions of relative parts while for irregular shapes such as curves and surfaces, associability is used to do the work in an assembly. Same merit applies to designs of other machineries, on reducing design time and design mistake, enhancing consistency and ease of documentation, therefore liberating designers from redundant day-to-day routine computer-paperwork to make more innovative contributions to their jobs. Several 3D design tools and database software were applied in the research.

Keywords: Design change automation, parametric design, design associability
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1. INTRODUCTION

In machine design, the process which takes place between conceptualization and the final blueprint may not be as straightforward as many believe. It consists of various steps, perhaps even multiple iterations, with each step taking a considerable amount of time. An "engineer's drawing" or "engineer's drawing on a napkin", is a rough hand-drawn representation without accurate dimensions. How the "Engineer's drawing" becomes "Engineering drawing" used to be the responsibility of people called drafters, or designers. Great advances in computer technology today make it possible for engineers to gain the added value of having deep knowledge and skill as drafters or designers. These advancements are closely related to the surge of new design software, from old 2D CAD software to modern 3D CAD software. In old 2D CAD software, a drawing is a collection of geometric elements (such as lines, points, and arcs) laid out on a plane. The elements, which are unrelated to one another, are used to determine the final prints [5] and cannot be modified unless the designer deletes and redraws them. Today, the increasing demand for flexible tools in 3d CAD software has led to Parametric Modeling becoming as a mainstream; making variations in the design process less difficult. This is traditionally called *Parametric Design* which "*is the process of designing in environment where design variations are effortless, thus replacing singularity with multiplicity in the design process. Parametric design is done with the aid of Parametric Models. A parametric model is a computer representation of a design constructed with geometrical entities that have attributes (properties) that are fixed and others that can vary. The variable attributes are also called parameters and the fixed attributes are said to be constrained*" [2].

In today's 3D CAD software, such as Pro/E, CATIA, SolidWorks, SolidEdge and Inventor, to name a few, the parametric model is known as Parametric Sketching. However, Parametric Sketching and drawing are not the same; "A sketch is a collection of geometry (lines, points, and arcs) coupled with relationships (parameters, equations, dimensions, sketch constraints, and construction geometry) laid out in a 2D format. These geometric elements are related to each other to reflect design intent. These sketches are used to define 3D geometry, which is then projected to 2D for final prints.” [5] This collection of geometries and relationships are then stored into a database. Later on if the designer changes some or all of the dimensions, the entire model accommodates to the new parameters. The greatest benefit of this technology is that it reduces the amount of time designers spend modifying designs, effectively helping these designs to manufacturers more quickly. The aforementioned database is usually in spreadsheet form, such as in Microsoft Excel. The design can therefore be controlled remotely, meaning it’s not necessary to make changes directly from the design software GUI (Graphical User Interface). In fact, the changes can be done directly from a text file or database software. The greatest achievement is that dozens or even hundreds of relative drawings can be linked or controlled by single text or database file. A change made in any part or assembly is automatically reflected in all associated parts and drawing sheets. For example, with the intuitive 3D grips functionality, designers can quickly make changes to a model and all related drawing views update automatically.

There are two major techniques for relating parts in assemblies: parametric design, which deals with regular shapes such as lines, circles, etc.; and design associability, which deals with curves that have many control points to link. Because of the great advancements in CAD, software companies or manufacturers have already developed special databases and interfaces for standard machine parts such as gears and screws. For example, designers may key in the number of teeth, modulus, helical angle, size of hole, etc. and the software will search for, calculate, and draw the exact gear the designer wants. However, the designers may have to develop their own system from the tools embedded in the CAD software when dealing with non-standard parts.

This paper discusses the techniques and real applications of parametric modeling and design associability. Thanks to the advancements of computer hardware and software, machine design and manufacturing processes have been greatly simplified and accelerated. This simplification has therefore allowed the achievement of operational efficiency by reducing the internal manufacturing cost and customer response time.

2. DESIGN CHANGE AUTOMATION

The design change automation request came from the Taiwan Filler Technology Corporation. TFTC, a major liquid-food-packaging-machine-company in Taiwan, has over 30 years of experience in designing and manufacturing of food and beverage machines. The company has various types of machines in their product line, including unscrambling, bottle rinsing, case washing, filling and capping, bottleneck trimming, packing, pallet loading and pallet unloading, and pre-treatment equipment. Their costumers include major beverage companies all over the world.

Fig. 1 is the outlook of a Bottle Rinsing Machine and Fig. 2 is a Rinsing-Filling-Capping Machine system. Each machine has hundreds of machine components in contact with the bottles.

Fig. 1: A Bottle Rinsing Machine. Fig. 2: A Rinsing Filling Capping System.
(Courtesy of TFTC Corp.)

Fig. 3 is one of the sub-assemblies in one of the bottle filling machines, in which hundreds of machine parts are in contact with the bottles in order to make a quick and smooth operation.

The requirement of customers is that the machines are able to deal with different types of bottles (Fig.4). For each bottle, TFTC has to provide a specific set of machine parts to handle its specific shape, accounting for more than a hundred parts in one machine.

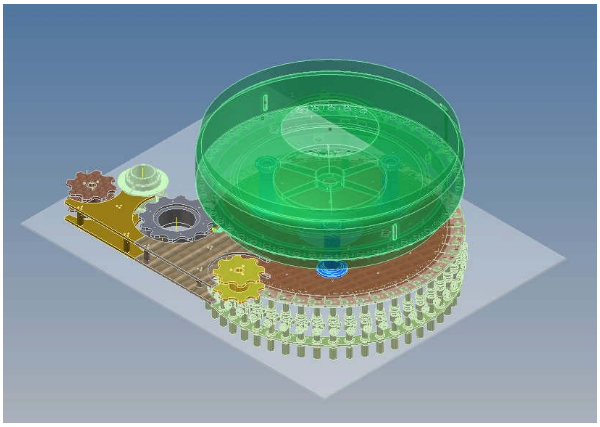


Fig. 3: First level subassembly of a bottle filling machine.

Fig. 4: Variety of bottles to be processed.

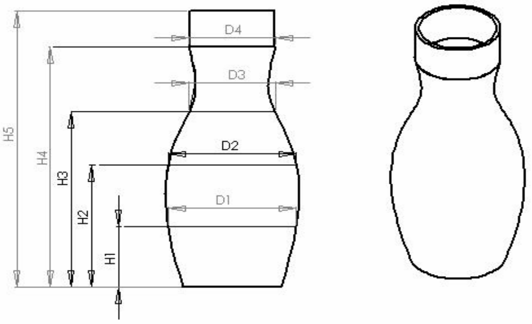


Fig. 5: Contact levels and diameters of the bottle.

Fig. 5 is the layout of one of these bottles. For each bottle, there are several levels for the machine components to come in contact, which results in a balanced and smooth movement. Although there are only five contact places shown in Fig. 5, up to 10 places may be used on a bottle if it has a more complex shape. For each bottle guiding plate and guiding wheel, there are three parameters to be changed according to the specific bottle. These include the height or level of the plate, the notch radius, and the thickness of the plate (Fig. 6). Because there are 10 different contacting levels on a bottle that has different diameters, thirty parameters must be changed in order to deal with the update of a particular bottle shape, assigning to hundreds of machine parts.

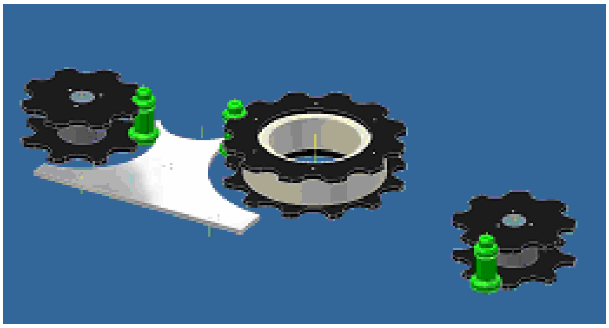


Fig. 6: Bottles in contact with guiding plates and guiding wheels.

A customer who has a new bottle design usually asks TFTC to provide corresponding sets of machine parts in a very short period of time. In a filling machine, for example, this could mean changing over 100 machine parts before the deadline. Before parametric design was available, designers had to change literally hundreds of 2D drawings in three drawing views, piece by piece, line by line, circle by circle, making the job of a designer repetitious and boring. This process was therefore not only time consuming, but particularly prone to mistakes. In comparison, with design change automation, the only task the designer needs to accomplish is to import the 3D model of the new bottle, assign different heights/levels for the guiding plates to contact, and sit back as the software finishes the rest of the job. The computer modifies the corresponding 3D models for all the relative machine components, updates the assemblies, and finally automatically creates a new set of engineering drawings, all with single click of a mouse.

3. PARAMETRIC SKETCHING

For machine parts with regular shapes, such as spheres, cylinders, and rectangles; all dimensions can be expressed by simple parameters. For example, a cylinder is defined by its center line position/orientation, its diameter, and its length. Usually, in a machine the centerline of a part is fixed (constrained) and the parameters for the cylinder are reduced to two. Most 3D CAD software today has the capability of storing the parameters into a database, such as a Microsoft Excel document, and later on read them in order to control the geometry of the part.

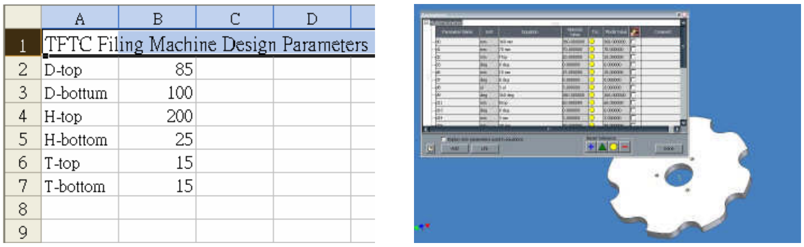
An example of the procedure used to build parametric sketches using Autodesk Inventor CAD software and MS Excel is explained below:

I. In the Autodesk Inventor environment, there is an embedded data-table which links all the parameters in the part or in the assembly;
II. When a 3D part is designed, by clicking the "Parameter" button, the embedded data-table appears with all corresponding parameters;
III. To link the external MS Excel file to the data-table, the only thing to do is click the "Link" button on the data-table and select the MS Excel file;
IV. When this is done, the embedded data-table updates automatically with the MS Excel data listed in it;
V. On this stage, particular parameters can be assigned to and later be controlled by the Excel data;
VI. Then close the parameter table and save the CAD file;
VII. To change the shape of the part, the corresponding values are first to be changed in the MS Excel file;
VIII. After saving the MS Excel file, the "Update" button should be pushed in the 3D CAD environment to activate the transformation of the shape.

Fig. 7 presents an MS Excel data table (on the left) and the 3D CAD environment screen with design parameters in the embedded data-table. The MS Excel table contains the following six parameters:

I. D-Top and D-Bottom: the diameters of the bottle, at both the up and down position, contacting with the guiding plates and guiding wheels;
II. H-top and H-bottom: the heights/levels of the guiding plates and guiding wheels on the machine;
III. T-top and T-bottom: the thickness of the guiding plates and guiding wheels on the machine.

The "remote control" of CAD design is realized by linking the external database table (Fig. 7 left) with the embedded database table within the CAD software (Fig. 8 right). In fact there are more parameters for a complete machine design, but only six parameters are listed in this example for clarity.



	A	B	C	D
1	TFTC Filing Machine Design Parameters			
2	D-top	85		
3	D-bottum	100		
4	H-top	200		
5	H-bottom	25		
6	T-top	15		
7	T-bottom	15		
8				
9				

Fig. 7: MS Excel parameter data table.

It is important to mention the limitations and provide tips for using parametric design, based upon the authors' experience. In order to create a valid pattern for a range of dimensions, it is necessary to apply the proper constraints (i.e. the relationships between all the geometrical components). A sketch containing multiple geometric components must be very well defined. Otherwise, if there are unconstrained points or a poorly defined relationship, when the parameters are changed, the geometric components will be misunderstood by the computer, causing the final geometry to be distorted.

Fig. 8 shows one of the situations in which the computer does not recognize modified dimensions properly. In this case, when the eight notches on a guiding wheel are drawn in a single sketch, the relationships between all the geometric parameters were not completely defined. As a result, the computer produces a distorted 3D extrusion during parameter change, shown on the right side if Fig. 8. As a matter of fact, for more complex geometry, completing such a sketch proves quite difficult.

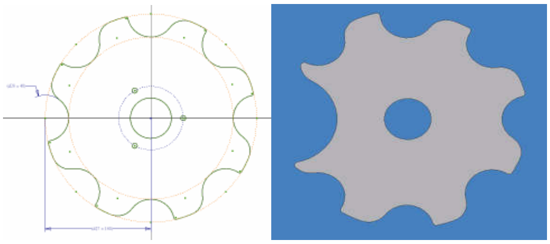


Fig. 8: Construction of the part based in one sketch.

The proper way to build the part is step by step, assigning each sketch to a specific feature, each sketch will control specific functions; such as extrusions, revolving, holes, arrays and fillets. In this manner, all the parameters are isolated and the geometries are well defined. An example of how to design a guiding wheel correctly is shown in fig. 9. In this procedure, a round plate with a hole in the center is created first (sketch 1). Secondly, a notch defined by the diameter of the bottle is cut (sketch 2). Then the eight-piece circular pattern for the notches is created (circular array). Finally, the sharp corners are smoothed out with fillets of different radii. By linking the notch radius with corresponding bottle diameter in the MS Excel table, the computer automatically creates and changes the shape of the guiding wheel, correctly and repeatedly, with no room for error.

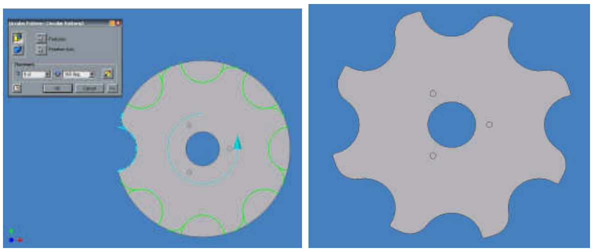


Fig. 9: Construction of a guiding wheel based in several sketches, circular pattern is used.

It should be mentioned also that in the software used, non-dimensional values are not accepted. However, in the real world, non-dimensional values play a very important part. Therefore, a named-unit-length has to be assigned and insert into the formula. For example in Fig. 10, one of the diameters equals the number of pitches “n0” multiplying by the module of the teeth “Module”, while the number of pitches is a non-dimensional value. Since the CAD software only recognizes any parametric value as “length”, it treats “n0” as length as well. Therefore, the computer “thought” the dimension of the diameter is mm^2 and sends out an error message. To overcome this barrier, a unit-length named “Module01” is introduced into the formula and the dimension of the “Diameter” keeps “mm”.

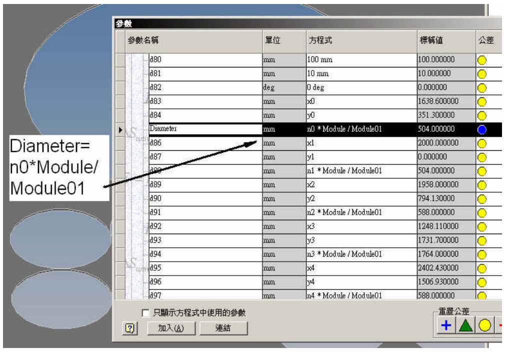


Fig. 10: Example of introducing a named unit length “Module01.”

Based on the above mentioned technology, the design of TFTC bottle filling machine is automated, including the engineering drawings. The example in Fig. 11 presents the effectiveness of the parametric design. Starting bottles with same diameter at bottom and top (left side, Fig. 11), the bottom diameter was modified (right side, Fig. 11). Simply by keying in the bottom diameter in MS Excel, corresponding changes in all 3D models took place automatically including the guiding wheels and guiding plates, without any mistakes or interference.

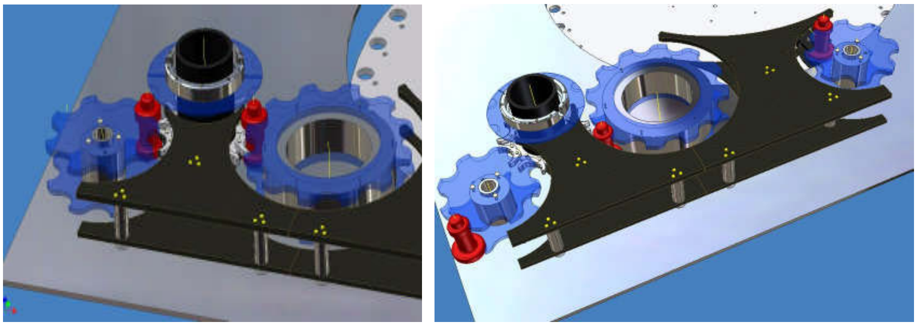


Fig. 11: Bottle guiding assembly automatically modified by bottle parameters.

4. DESIGN ASSOCIABILITY

It is difficult for irregular shapes such as the curves and surfaces to be simply represented by circles or lines that could then be presented by parameters. Therefore, design associability is used to solve the problem. Fig 12 shows two examples of irregular bottles shapes. In order to design grips to handle the bottles, the surfaces contacting the bottle have to conform to the bottle shape.

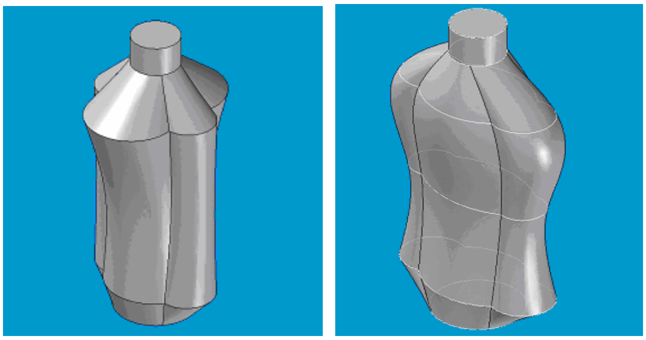


Fig. 12: Bottles with irregular shapes.

The cross-section of the bottle varies continually in the height direction, therefore, no single parameter or group of parameters are enough to represent the complex geometry (Fig. 13).

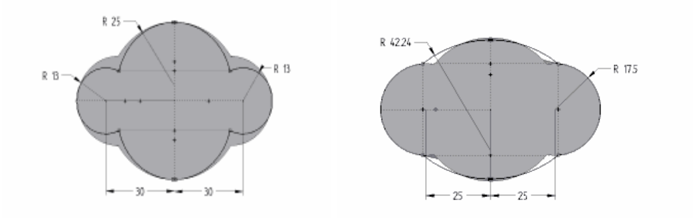


Fig. 13: Cross sections of above bottles at different height/level.

One of possible methods is illustrated through Fig. 14 to Fig. 15 and the brief description using SolidEdge CAD software is as follows:

I. Starting in assembly environment, *insert* the 3D model of the bottle;
II. Still in the assembly environment, *create a new part*, in which one of the grips is to be designed;
III. Then in the part environment in which the image of 3D bottle is appear, click *copy between parts* to fetch the desired surface of the bottle (fig. 14);
IV. Finally, by extruding from a rectangular plane to the surface, one side of the grip is formed (Fig. 15)

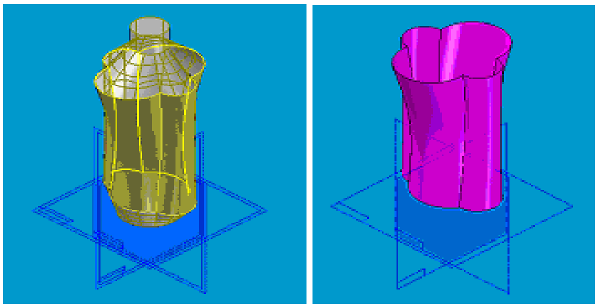


Fig. 14: Steps in design associability (1).

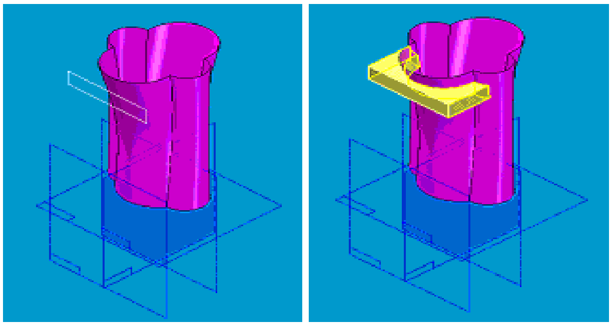


Fig. 15: Steps in design associability (2).

Since the corresponding surface of the grips are associated with the bottle, whenever the shape of the bottle changes, the grips change automatically. Examples of results are shown in Fig. 16.

5. RESULTS AND DISCUSION

Design change automation is achieved through parametric sketching and associability in 3D CAD. The former is used for regular shapes (i.e. circles, lines), while associability is used for irregular shapes and curves.

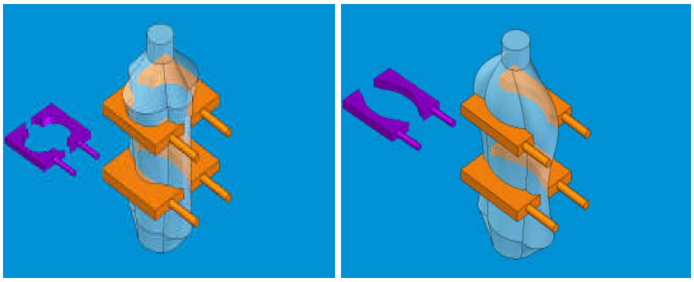


Fig.16: Bottles with irregular shape that have to use design associability for the grips.

One of the experiences learned from the project is that, in order to create stable parametric models, it is necessary to create features such as extrusions or revolving solids in a step-by-step fashion. Also, each feature is suggested to be linked to a simple sketch with variable parameters. Moreover, to involve more geometrics elements in once sketch, restrictions and relations between the geometric elements must be fully defined.

These technologies have brought a fundamental change in the TFTC design department and given the company great benefit. Without the design-change-automation, designers of the company have to modify hundreds of 2D AutoCAD drawings to suite every new bottle shape in a very short period of time. Multiplying the number of lines and circles in each drawing, thousands of sketch elements have to be changed to suit a single new bottle shape. Not only does this cost a lot of repeated drawing work, but also easily causes design mistakes that cost more labor and money in fabrication. Therefore, the technology proved to have great potential on reducing design time and design mistakes, enhancing consistency and ease of documentation. This in turn liberates designers from redundant day-to-day routine computer-paperwork to make more innovative contributions to their job. The great impact of the technologies on machine design work is undeniable.

6. ACKNOWLOGEMENT

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