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Generative Modelling Technique Application for Unfold Surface Designs

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Abstract. The design process for objects which feature some unfold surfaces is a specific branch of enginnering design. An unfold surface is defined as a surface which takes many forms which are dependent on, for example, a skeleton structure, the material's property etc. As an example, the membrane of an umbrella can be used. A combination of surface modelling and parametrisation makes the unfold surface design process very complex and difficult. The need for modelling of such types of elements in their various positions presents many different problems. One such problem, surface area value continuity, is described in this paper. The varying range of problems related to the design process means that in many cases elements which feature an unfold surface are skipped during the design process or are simplified. In this paper, authors make an attempt to deal with this design problem. In the paper, authors present a novel approach which is based on a distributed model where the main part of the presented model is a generative model. The use of generative modelling techniques allows for automatation of many tasks which normally must be done manually by the designer.

Keywords. Generative Model, Distributed Systems, Unfold surface, Trailer tarpaulin, CATIA V5

Introduction

The introduction of Computer Aided Design (CAD) systems was a milestone for modern engineering. The possibility of developing a three-dimensional virtual model that can be used for example for manufacturing automation or pre-manufacturing validation of a product is priceless [1][2][3]. But now, although engineers have many dedicated modules, not all objects are designed. Usually objects which are not designed require a lot of specialist knowledge and since CAD systems use experiences, these objects are skipped during the design process or are just simplified [2][4].

An example of the specific objects that create a lot of problems during the design process is objects featuring unfold surfaces. In this paper, the authors define an unfold surface as a type of surface that can take various forms depending on use conditions, material properties, etc. [5]. As is shown in Figure 1, an umbrella can be an example of an object that contains unfold surfaces. As can be observed, the membrane part of an

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umbrella takes different shapes depending on the umbrella's skeleton structure, which causes many problems when designing this kind of object. In later parts of the paper some critical problems are indicated and described.

Figure 1. An example of an object that features an unfold surface.

1. Problems with unfold surface design

Designing unfold surface elements is a difficult and specific task. During the process, an engineer must control a various range of parameters and requirements to create a model representation of at least two basic stages – folded and unfolded.

One of the biggest problems is the prediction of how the to unfold surface will behave during the folding and unfolding process. Many factors influence the way the surface will be lay. A one of the most important factors is the form of the support structure [5].

Making a detailed analysis of the support structure allows for definition of a few important pieces of information that are necessary for the design process. One of those pieces of information is the boundary conditions for the designed element. The boundary conditions determine the areas of when the structure and material are fixed together and when the position between them is unchanged. This situation insinuates that a mathematical model of the unfold surface must be constant in those areas or change only in the very limited way [5][6].

Additional information that comes from the support geometry is about mechanical aspects. Knowing how the mechanism works are very helpful in the process of determining the shape of the unfolded and folded surfaces. Depending on how the support structure acts during the folding and unfolding process, the surface will behave in different ways [5][6][7].

Another factor that must be considered in the unfold surface design process is from what type of material the surface is made. The material's stiffness is key information that is necessary to predict the shape of the folded surface. Usually, the unfold surfaces are made from soft materials which can be easily folded and unfolded. Because of that, modules developed for the SMD (Sheet Metal Design), which allows presentation of a model in two extreme positions – folded and unfolded, are completely useless. In Figure 2 is shown SMD's ability to create a representation model in various forms [3][4].

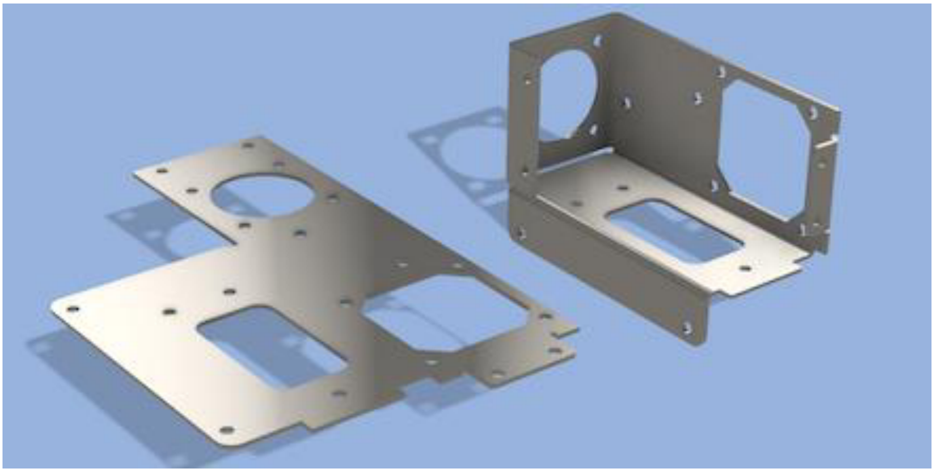

Figure 2. An example of a model elaborated in the SMD module.

Another problem that a designer must face is how to ensure that the surface in both stages, folded and unfolded, maintain the same area value. This is important because during the folding and unfolding process the amount of material is constant. To make sure the constant area condition has been fulfilled, equation (1) must be satisfied[5][6][7].

$$\iint_S f(x,y,z)dS_u = \iint_S f(x,y,z)dS_f \tag{1}$$

Where: $f(x,y,z)$ – function describing the surface, S_u – area of unfolded surface, S_f – area of folded surface.

The application of mathematical methods based on integrals generates a few problems which must be solved. The first and biggest problem is knowing the function which describes the surface. Considering that these kinds of surfaces usually are complex and depend on many different factors, it is not easy to elaborate on the mathematical model for such an object. Some simplifying must be done to make this task possible to solve [6][7]. One kind of simplifying is an approximation of boundary curves by standard mathematical functions such as trigonometric functions, quadratic functions, etc. This procedure allows for easier calculation and reduces the time of calculation. Reduction of the calculation time is important, especially because the numerical calculation of integrals requires a lot of time for a high-quality solution [7].

The last problem described in this paper is related to software issues. It is highly difficult, or even impossible, to carry out the whole process in only one program. Bearing in mind the previous considerations, at least two different types of software are required. The first type is CAD software where the model will be developed [3][5]. The structure and type of input data that must be provided to the CAD system depend on the chosen software what additionally means the solver software must be compatible. In other cases where incompatible systems are used, data transfer between the programs will be difficult and can cause some extra work [2][5].

The second type of software is a software used for solving the mathematical aspects of the task. For this type of software, it is required to be able to run complex optimisation tasks where the objective function includes integral calculations. As was mentioned previously, CAD and solver software should be compatible and easy to integrate with each together. The compatibility allows for direct data transfer and greater control over the process.

Based on what is mentioned in this part of the paper, a conception of a distributed system was proposed. In the fourth part of the paper, the next parts of the system are described, with a special focus on CAD software issues.

2. The concept of a distributed system for unfold surfaces

The unfold surface design process is a complex design task that requires a specific approach. The significant number of issues described in the previous section of the paper forces the use of more than one software. The authors' approach is based on a distributed system that combines a few different programs. In Figure 3 is shown the concept of the authors distributed system with data flow to deal with the unfold surfaces problem.

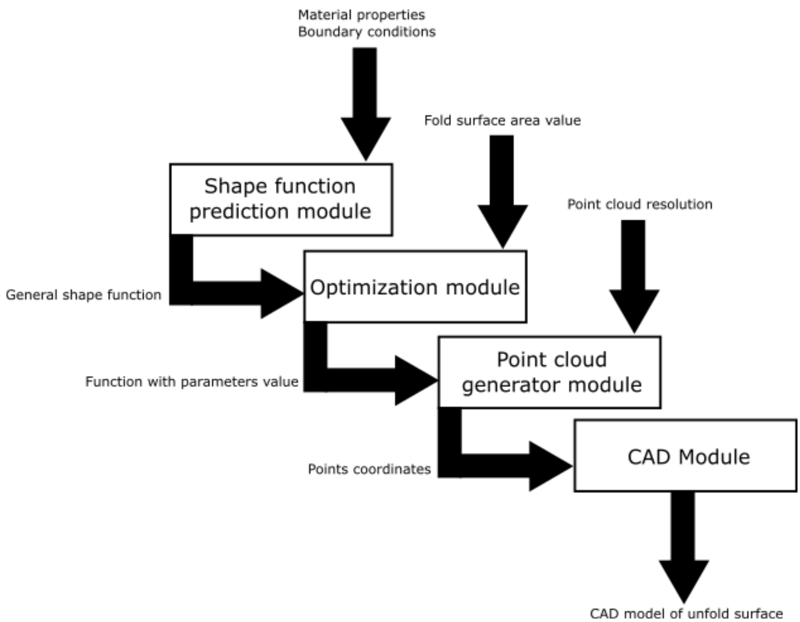

Figure 3. The conception of the distributed system for unfold surface design.

As it is possible to see in Figure 3, authors propose a distributed system which features four modules. The first module is a shape function prediction module. This module is intended to predict what function will most accurately describe the shape of the surface [8][9]. This part of the system is the most difficult because it must be developed for each use case. Authors intend to use a belief network such as the Bayesian network to estimate a probability for previously determined shape functions.

Based on information provided by the user such as material stiffness, boundary condition, etc., the system should be able to highlight a function with the highest probability that the surface will take such a shape [5][8][9]. In Figure 4 is presented an example Bayes network that can be used to describe the paper's purpose.

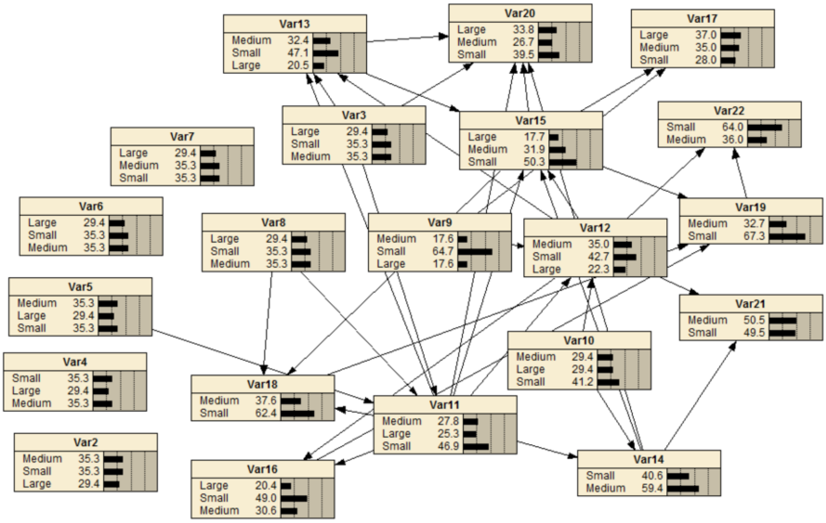

Figure 4. An example Bayes Network.

The second module used in the proposed distributed system is the shape function's optimisation module. The main goal of this module is optimisation of the shape function's parameter values [11][12]. Based on a general function form from the first module, the optimizer must find the proper values of the function's parameters in order to satisfy the area continuity requirement. In Figure 5 is presented the simple Monte Carlo based algorithm for parameter values searching [11][12][13].

Another module that the authors propose is a point cloud generator. The generator is a simple program which, based on a function and parameters values received from the previous module, creates a file where point coordinates are saved. An additional information in the point cloud generator is the solution's resolution. A user can set how many points should be in the cloud; a larger number of points needs more time and space to be properly computed. Furthermore, the points generator must save coordinates in the proper format which would allow for its use in the next module.

The last module in the distributed system is the CAD module. In this module the surface is elaborated on based on the point cloud. Most modern CAD software already has dedicated tools for point cloud elaboration, but these tools are useless in the case where the surface will frequently be updated [14][15]. To develop the CAD module, authors decided to use a Generative Model (GM) which will automatically generate the surface based on the coordinates file from the point cloud generator module. In Figure 6 is presented a schema of a standard Generative Model. As is possible to see, this kind of CAD model has integrated knowledge that allows automation of the process of model development. In contrast to a classic parametric model, the GM is not a self-existing model and to use it, a start file that contains input elements (geometry and parameters) is required. The additional and main differences between a parametric model and a GM is that the GM must have integrated knowledge which is a core element of this type of model.

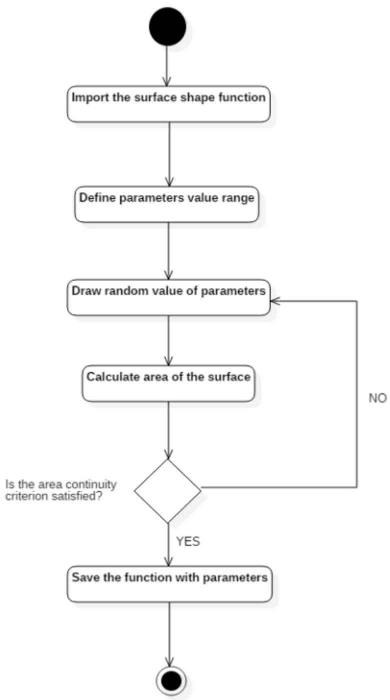

Figure 5. The algorithm diagram for the optimisation module.

In the unfold surfaces case, knowledge related to the material properties and a current use case are required [2][4][5]. Different knowledge is needed when a car's soft roof is designed than when an artificial heart valve is being designed. Because of that, some additional work must be done to adapt the Generative Model for different use cases. Usage of the GM makes it possible to update a developed model for example by changing the point coordinates, which is impossible when standard tools are used. In the next part of the paper a use case that shows the Generative Model usage is described [1][2][14][15].

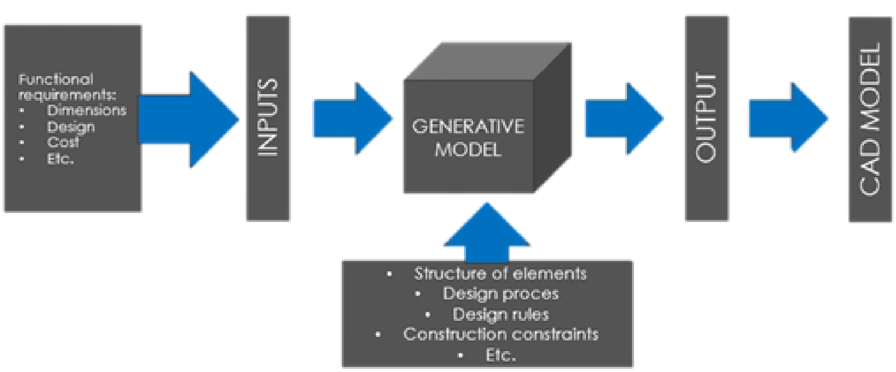

Figure 6. A standard schema of how the Generative Model works.

3. Use case for a trailer tarpaulin – a Generative Model usage

An example of the proposed distributed system usage is a trailer tarpaulin. A trailer tarpaulin is an object that is used to cover a trailer and to protect cargo. In Figure 7 is presented a truck model with a side slide tarpaulin.This kind of a trailer tarpaulin is a very popular solution for trucks covers because it provides wide access to the cargo zone from the side of a trailer. Now companies that design this type of trailer usually skip the tarpaulin in the project or design it in a simple one surface form. Authors intend in this use case is to show how a properly prepared Generative Model can be useful in this design situation.

Figure 7. An example of a truck with a side slide tarpaulin.

In describing the case use, authors assume that the tarpaulin in its unfolded form is a simple rectangular shape surface. This assumption allows easy calculation of the unfold surface area value. Next, a simplification was made by authors that the folded surface has a harmonic function shape described by the formula (2).

$$y(x) = A \cdot \cos(2\pi \cdot f \cdot x) \tag{2}$$

Where: A – amplitude, f – frequency

As is possible to see, the authors decided to convert the tarpaulin problem into a two-dimensional problem. This simplification is used because it is reasonable to assume that the tarpaulin's surface is constant along its height. Thanks to that, all simplifications of the optimisation module must solve equality between the fold and unfold curve lengths.

In the unfolded form, it is easy to measure the curve length as it is a straight line, but in the folded form, special mathematical methods must be used. To calculate a length of a curve described by a harmonic function, it is necessary to find the first derivative of the function and use it in formula (3).

$$L = \int_{a}^{b} \sqrt{1 + f'(x)^2}\,dx \tag{3}$$

Where: L – length of the curve, a and b – start and end points of the surface measure in a straight line, $f'(x)$ – first derivate of the surface shape function

Knowing all mathematical aspects of the problem made it possible to set the optimisation module to find the proper shape function parameter's value. In Figure 8 is presented a chart of the optimisation process results. The optimisation goal function was to find a value of frequency and amplitude for formula (2). The parameter's value must meet the condition that the length of a folded surface will be equal to the length of the unfolding surface. On the chart, the blue curve is for the frequency parameter in the range 0.01Hz to 10Hz, the green curve is for amplitude parameter in the range 10mm to 250mm, the yellow curve for the best solution and the red one for current length.

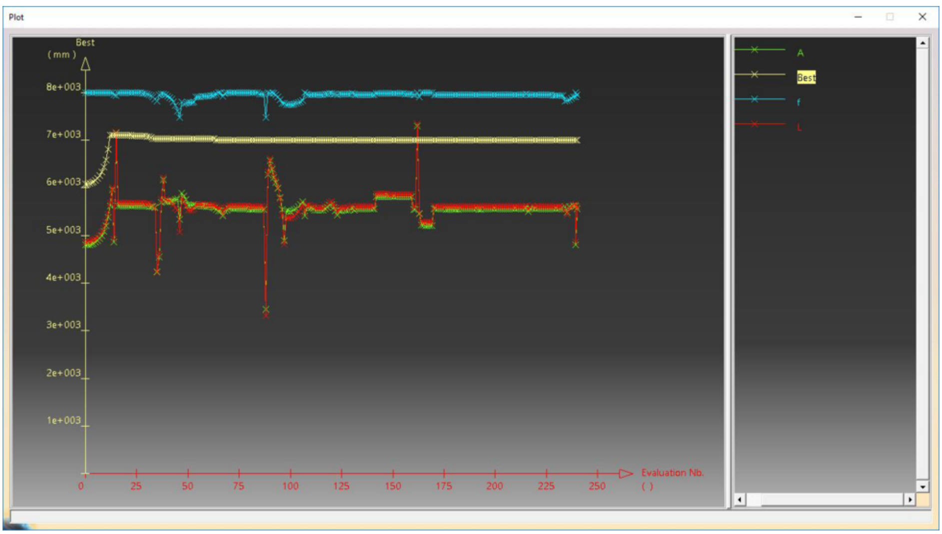

Figure 8. The chart with optimisation process results.

Based on the optimisation module calculation results, a point cloud was generated. All points coordinates were saved in a Microsoft Excel file. The next stage of the surface elaboration was the use of a specially prepared Generative Model. In Figure 9 is presented the user form of the model. As is possible to see, the model was used as input data using the Excel file with the point cloud coordinates. The elaborated model allows for surface generation and future updates when any changes must be included.

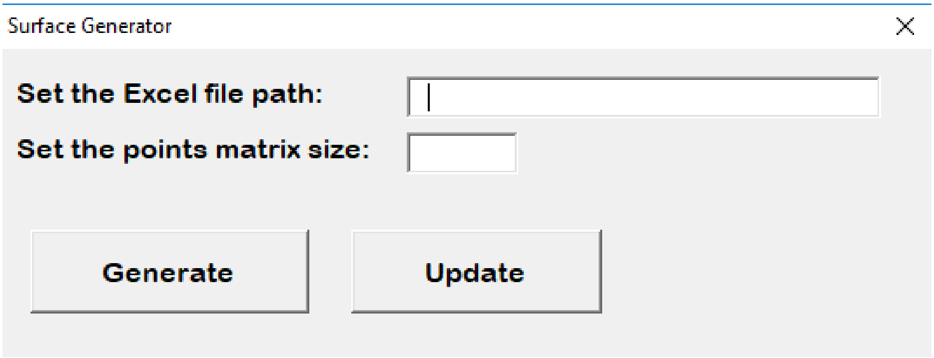

Figure 9. The surface generator user form.

The main task of the model is the generation of points based on coordinates from the input file. The next step of the GM's activity is to connect previously generated points used for this as a spline curve, and to next generate a loft surface. In Figure 10 are shown the results of the GM model usage. The brown surface is a representation of the unfold surface and the blue is for the folded surface.

Figure 10. The result of GM action.

Presented in this use case example is a simple example to highlight the methodology used to deal with the introduced problem. The offered solution can be transferred to more complex issues such as an airbag or a convertible roof. In cases of more complex problems, mathematical description is a much more demanding task and requires extensive mathematical knowledge of the surfaces and curves.

4. Conclusions

The presented paper is an attempt to deal with the unfold surface design problem. A lack of dedicated modules in current CAD software forced authors to find a solution of this kind of design problem. The presented solution is based on a distributed system that features four special modules. Elaborations of each module bring a lot of different problems that must be solved. One of the biggest problems is prediction of how the material will be shaped. It is a complex problem and requires a lot of information about material properties and boundaries conditions.

Based on the authors' own experiences with the generative model, they have proposed the approach that uses the GM as one of the main components of the distributed system. The GM allows automatization of the surface generation process and reduces the time needed to design this kind of object.

It must be noted that the problem of the unfold surface is quite common in specific engineering branches like automotive or aerospace, where elements must be designed to finish the project and where full documentation is made.

The presented use case is only one way to use the presented system. Another area where this solution can be used for example is in the medical industry, with an artificial heart valve or stents feature for unfolded surface elements. Solar sails that are used in space probes and space telescopes are also objects that contain this types of surface.

The next actions for the authors on the system is further development of proposed modules. The shape function prediction module is a key module that needs special attention for its proper design. Additionally, finding a solution for the optimisation module to make it more flexible is another important task. The best developed module so far is the CAD module that is based on the Generative Model.

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