

# INTERACTIVE SPLINE MODELLING OF HUMAN ORGANS FOR SURGICAL SIMULATORS

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**Abstract.** This paper investigates a new method of interactive modelling to approximate position and shape of real patients' organs. The method is particularly successful in that it greatly reduces the time needed to create patient specific models. KisMo [1] is an interactive graphics based modelling software for creating 3D models with elastodynamic behaviour for use with VS-One - the Virtual Endoscopic Surgery Trainer (VEST) developed by the Institute for Applied Informatics (IAI) at the Forschungszentrum Karlsruhe. Software modules have been designed and implemented to enable interactive and intuitive modelling of closed spline curves on tomographic image data (CT, MR), which form a closed spline surface approximating position and shape of real patient organs.

## 1 INTRODUCTION

In the past CT and MRI volume data sets have been represented as a series of 2D slices. Volume rendering [2,3] is an alternative technique that increases the users ability to view the data. These different representations of the volume data greatly affect the user's ability to visualise hidden structures.

Most of the traditional methods of modelling rely upon edge following techniques to create contours that map a surface to the volume data. Taylor et al. [6] describe a method of positioning a set of geometrically defined 2D slice probes along an organ's centreline; the 2D slices of data represent cross-sections of the organ. The use of thresholding and level set methods [4] on the 2D slices provides a set of contours that, when interpolated, result in a finished model. An alternative technique by Miller and colleagues describes a method of extracting closed geometric models from volume data [5]. The geometrically deformed modelling technique employs a simple predefined object that is deformed based on a set of constraints. The initial stage of the modelling process involves either embedding into or surrounding the required organ with the predefined object. The predefined object then grows or shrinks to fit the organ within the volume.

Since the human body is mainly made up of a variety of organs, the medical consequence of organ modelling is very important, ranging from heart surgery to minimally-invasive surgery. Surgery planning for predicting the outcome of surgery or rehearsing complex operations requires an accurate representation of an organ. It is

therefore essential to improve the accuracy of the modelling process.

By using an interactive modelling process it will be possible to create more accurate patient specific organ models. Additional benefits include a reduction of time needed to create a specific model, with reduced user input being replaced by better use of body scan data. If successful the accurate representation of the physical human form, more specifically the realistic modelling of the internal organs, will not only improve current simulation systems but will also enlarge the applications of medical simulation resulting in improved performance and reduced training costs.

The rest of this paper is organised as follows: Section 2 describes the interactive spline modelling technique while Section 3 goes into some implementation details. Section 4 presents results and Section 5 concludes the paper.

## 2 INTERACTIVE SPLINE MODELLING OF HUMAN ORGANS

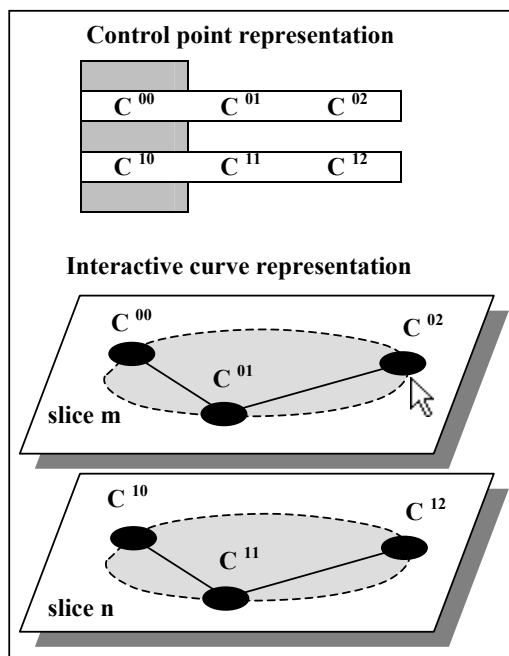
Before the completion of this work KisMo [1], the interactive graphics based modelling software for creating 3D models with elastodynamic behaviour (developed in C++), consisted of three predefined shapes: the flat, the pipe, and the ball, each of which is constructed from a spline surface. Volume rendering is used in KisMo as a modelling aid for the approximation of location and shape of organs inside of medical image data.

KisMo achieves a high level of flexibility by representing its predefined objects as individual spline patches. A total of four control points - each

with their own derivatives and interpolation points - are used to define a surface patch. The interpolation points can be described as representing a sub-patch. Like the control points the interpolation points can be interactively positioned so as to increase the level of accuracy possible.

The recognised technique of placing a vector inside of a vector has made possible the creation of a matrix structure. The matrix structure is used to hold control points and the control points in turn hold their own matrix of interpolation points. This has been made possible because although both matrices are derived from the same class and use the same member functions they are instantiated with different types. Therefore the matrix structure can be thought of as a container of containers. Specific functionality implemented in the matrix structure includes:

- Append and delete from the end of the structure.
- Insert and remove from anywhere in the structure.



**Figure 1 Model representations**

Figure 1 shows the matrix and interactive curve representations of a model. When coupled with mouse interactions the additional functionality provided by the matrix enables the user to build a model interactively by placing control points directly at their required location thereby removing the need to morph a predefined object. A list

containing the slice numbers of a volume data-set at which accepted curves are positioned is also kept, this list is used to determine the position of the currently accepted construction curve as it is appended or inserted into the surface matrix.

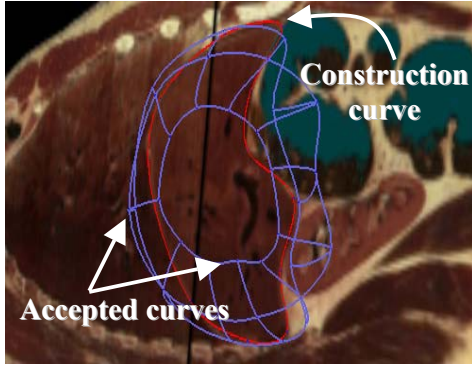
To create an accurate model of an organ several series of connected control points that form curves can be placed on individual volume slices. The user constructs a curve by placing moveable control points on a slice in an ordered fashion to ensure that twisting of the model does not occur. To increase the accuracy of the modelling process moveable interpolation points are placed between control points. These interpolation points are also stored in a matrix structure and therefore have their own special cases. These special cases are similar to those experienced during the adding and deleting of control point in that they appear during the same operations: when the very first control points is the subject, when a control point between two existing points is the subject and when the end control point is the subject.

### 3 IMPLEMENTATION ISSUES

A construction curve is used to outline an organ in the volume dataset and appears as in red, the currently selected control point also appears red in colour. The construction curve allows the user to add, remove and drag control points as required. Control points are either appended or inserted depending on the position in the construction curve of the currently selected control point.

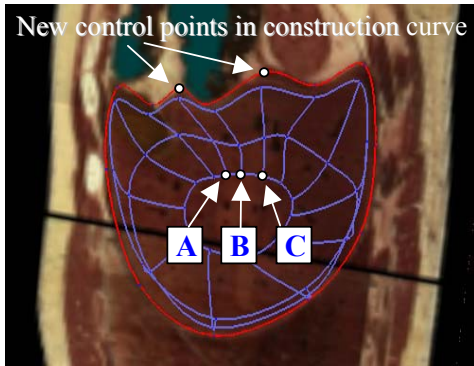
A user is free to move through the volume dataset using a volume rendering dialog box and can accept a complete curve on any slice that does not already contain a curve. A curve is either appended or inserted into the surface matrix depending on the position in the interactive surface of the current construction curve.

Figure 2 shows that a relatively accurate interactive surface can be constructed, after a short period of appending and inserting curves to the surface matrix. When appending or inserting curves to the surface matrix the new construction curve is always a copy of its neighbouring accepted curve and therefore appears in the same position. The position at which the accepted curve is to be inserted is determined by looping through the slice number list until a value greater than that of the slice number of the construction curve is found, the construction curve is then inserted before this position.



**Figure 2 Several curves added to the interactive surface**

A guessing algorithm has been implemented to minimise the work required by the user to drag control points of a newly appended or inserted curve into their required positions. A simple linear interpolation between two existing curves is used to guess the position of the control points in the construction curve. Clearly, the smaller the distance between accepted curves the more accurate a guess will be achieved. In most circumstance new curves are appended to the end of the interactive surface, in these cases the guess algorithm creates a copy of the outside curve to which the construction curve neighbours. In some situations the user may wish to finely adjust the positions of control points of an already accepted curve. Moving the construction curve to a slice containing an accepted curve that requires updating will cause the control points of the accepted curve to turn to green. Fine-tuning of the accepted control points is now possible.



**Figure 3 Adding control points through the interactive surface**

Figure 3 shows that an example where a number of curves have been accepted and where in order to maintain an accurate interactive surface two extra control points have been inserted into the construction curve. To maintain a working data structure, two complete columns of control points (A) and (C) have also been inserted into the surface matrix. A control point that is appended (C) to the

construction curve has its position set at the mouse coordinates, all other control point positions in the appended column are set as

$$\forall i: C^i = B^i + (B^i - A^i)$$

Control point (B) that is inserted into the construction curve also has its position set at the mouse coordinates, all other control points positions in the inserted column are set as

$$\forall i: B^i = 0.5(A^i + C^i)$$

This method of appending or inserting means that control points are placed at positions that require the minimum amount of adjustment by the user in order to drag them into their correct positions.

Each control point has a number of interpolation points associated with it. The position of these interpolations is calculated from control and derivative point positions. It is possible for the user to change the number of interpolation points in a given section of the spline surface during the modelling process. The number of interpolation points of each model in the simulation scenario has to be adapted to the capabilities of the used hardware to guarantee real-time object deformation simulation.

Once the modelling process has been finished, the user has the option to finely adjust the finished model by repositioning individual interpolation points so that a more accurate representation of an organ's boundary can be made. Vectors that start at the control point's centre are used to define the derivative points. The derivatives can also be used to control the shape of the curve at a control point. Once activated the user can grab a derivative and change the shape of the curve at the host control point.

The modelling operations can be performed on slices in all three geometric viewing planes thus the user has the ability to choose a modelling orientation which best suits the model to be produced. This is desirable since certain orientations of a given organ are easier to model than others.

Many of the operations performed on the matrix representation of the model described in this paper - append, insert, delete and remove - are available in the Standard Template Library. However implementing them as member functions of a custom-built data structure enables additional functionality to be added at any time making the matrix structure a practical approach.

## 4 RESULTS

The new modelling technique was used to model the liver of the visible human as an elastodynamical object and test the object deformation with VS-One, the Virtual Endoscopic Surgery Trainer (VEST, shown in Figure 4) developed by the Institut für Angewandte Informatik (IAI) at the Forschungszentrum Karlsruhe in co-operation with Select-IT VEST Systems AG, Bremen-Germany.

The system provides an input box with force-feedback instruments and an endoscopic camera mock-up. The instrument and camera positions are tracked and due to the user's interactions in the virtual world, forces and torques are calculated and transmitted back to the input devices.

The surgical scene is specified in a hierarchical model-database in which the geometry of the objects, their elastodynamic behavior, and the kinematics of the instruments are defined. Deformable objects form the foundation of the surgical simulation. Their behavior is defined by physical characteristics like mass, stiffness and damping. Real-time collision algorithms enable the trainee to manipulate deformable objects using a physical instrument set and perform virtual interactions.

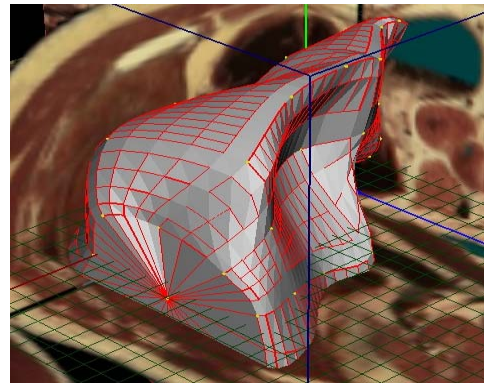


**Figure 4 VS-One – The Virtual Endoscopic Surgery Training System**

KISMET (Kinematik Simulation, Monitoring and Off-Line Programming Environment for Telerobotics) is a visualisation and simulation software developed at Forschungszentrum Karlsruhe. Because of its capabilities KISMET was found to be an ideal simulation platform for

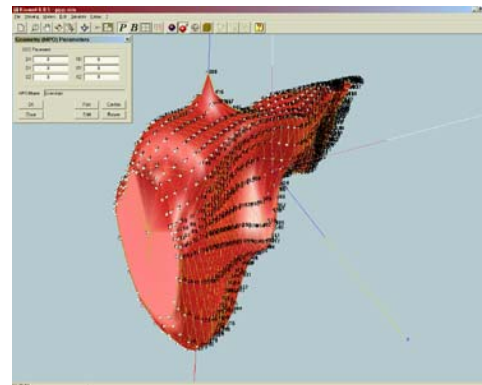
computer aided surgery and is used in VS-One. It provides a rich set of virtual surgical instruments used for simulated grasping, clipping, cutting, suturing, tearing tissue, irrigation and suction.

The visible human dataset was used to approximate the correct location and shape of the liver. KisMo supports multiple image data formats but also DICOM, which is a standard image format produced by CT- and MR-scanners. This enables the use of any patient's body scan to create a simulation scenario with deformable objects for surgery training with individual patients' organs.



**Figure 5 Model of the liver of the visible human in KisMo**

Figure 5 shows the modelled liver in the visible human data set. KisMo automatically creates a mass-spring mesh for object deformation simulation for any modelled object. The deformation parameters can be set by the user and managed in a physical properties database.

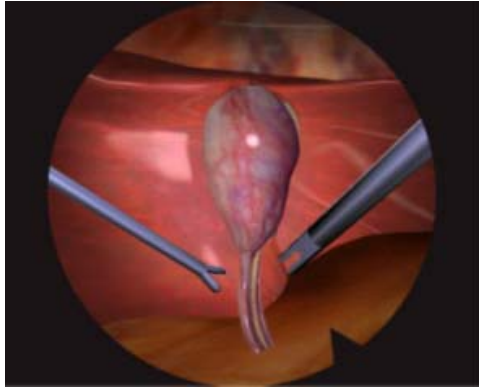


**Figure 6 Deformation simulation in KISMET: Testing the physical parameters**

Any created model can be stored in a model-database and re-used for creating new simulation scenarios. After exporting the model to the simulation software KISMET the deformation parameters can be tested. Figure 6 shows the modelled liver during the deformation simulation in KISMET. The mass-spring mesh is visible; a mass

knot is picked and elongated, which causes the object to deform.

Building a simulation scene needs modelling the organs and setting up correct physical parameters, materials and textures. Finally an inter-object connection has to be defined to enable interactions between the objects. After exporting the scenario to the *VS-One* system with the provided virtual surgical instruments the trainee can practice the operation. Figure 7 shows an example of a training session on virtual cholecystectomy.



**Figure 7 Realistic simulation scenario for cholecystectomy (gallbladder removal) in *VS-One***

## 5 CONCLUSIONS

This paper describes a method for accurate recovery of patient specific organ models for use in surgical simulation. The new modelling technique introduced produces significantly better and suitable models for surgical simulation than semi-automatic segmentation and reconstruction methods. It enables a high degree of interactivity and full control over the model generation. The modelling person, who should have medical background, can use his expert knowledge to identify structures and create accurate organ models.

Another advantage of this method is that a physical layer of the model is generated automatically during the modelling process, which enables deformation simulation, whereas segmentation and reconstruction methods only generate static 3D-models.

One benefit of our new modelling technique is the small amount of time needed to generate a basic model from a volume dataset. The full elastodynamical liver model in Figure 5 was created in less than 8 minutes by an expert user.

Future work should concentrate on better guess functions which also use image data information to speed up the modelling process and the quality of models.

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