VisAEffect: the software tool for 3D vector and scalar field visualization with texture animation

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Abstract

This paper presents a new software tool for 3D steady vector and scalar field visualization called VisAEffect. The visualization methods, which were implemented in this software tool, are described. The description of the structure, functional capabilities and interface is given. The method for flow field animation by Motion Map was used in VisAEffect. The technique for rendering of the vector field third component in visualization of 2D section is proposed. The optimized palette, which allows avoiding distortions and ambiguities in color coding of scalar data, is presented.

Keywords: *Visualization, Scalar Field, Vector Field, Software, Texture Methods, Motion Map.*

1. INTRODUCTION

The visualization of data about vector and scalar fields is an important branch of Computer Graphics. The most challenging task here is the 3D vector field visualization, because we have no appropriate visual analog of such an object in nature. In the last decay a lot of effective vector field visualization techniques were proposed. However most of the visualization software environments implement such traditional methods as arrow plots and a set of individual streamlines, which have several drawbacks and present information with a low resolution. Therefore the development of new visualization software tools with the last advantages is actual and important.

The main problem in vector field visualization is an amount of information that needs to represent (the magnitude and direction of vectors in each point of field). We can trace some evolution of methods by publications in the area of scientific visualization. The traditional approach to draw vector fields consists in application of arrows [5][13] or another symbols: the probes of vector field [10]. Such approach can represent only a little part of information about field, namely information in locations of probes. Moreover some problems concerned with arrows crossing or alignment of arrows in regular structures can arise in these methods. The techniques for creating of streamlines [8], stream tubes [11] and stream surfaces [7] made it possible to represent vector field topology in more detail. However in these methods information about vector field between such objects remains undefined. After invention and further development of texture methods [3][14], which imitate particle streak images for the particles randomly dispersed in the fluid, the possibility of rendering in one image almost all information about 2D vector field appeared. The resolution of field direction sign was made possible after implementation of texture animation [6].

This paper presents VisAEffect: the software tool for creating of visualization of 2D section of 3D steady vector and scalar field in interactive mode. On the stage of software tool development after publications review the preference was given to texture methods of vector field visualization. These methods have an important advantage: the possibility to visualize both global topology of field by drawing of streamlines and local information in every point of the field. Moreover, the space resolution for texture methods is restricted by the size of a pixel only. In described software tool the vector field visualization is based on texture animation method [9]. In the beginning the VisAEffect was developing for visualizing of output data of 3D Azov Sea hydrodynamic mathematical model [4]. For this reason and for practical needs a possibility to visualize the scalar data was added in the software tool, although main researches were given for visualization of vector fields. Scalar field visualization was implemented by means of a popular color coding method with a special palette. Vector field visualization was realized for fields with arbitrary boundary. Such visualization is necessary for correct rendering of fluid flow fields in water objects, which have in general case non-convex boundary. This boundary is determined by floor shape.

Farther in section 2 the description of visualization methods, which was proposed and implemented in VisAEffect, is given. Section 3 describes the structure, interface and functional capabilities of software tool.

2. IMPLEMENTED METHODS

Following visualization methods were realized in VisAEffect:

- Motion Map: the texture method for 2D steady vector field visualization with animation.
- The streamline construction algorithm for vector fields with arbitrary domain boundary.
- The third component rendering method for effective visualization of 2D sections of 3D vector field.
- The optimized palette for better representation of scalar data by color coding.

Let us consider the basic ideas, features and advantages of those methods.

2.1 Motion Map

The method of 2D steady flow animation by Motion Map belongs to a group of texture visualization methods and was developed by Bruno Jobard and Wilfrid Lefer in 1997 [9]. This method is based on data structure named Motion Map, which contains the information about topology and magnitude of vector field and is used for creating of animation of texture splats along streamlines.

The Motion Map is a 2D array of cells with the same size as the final image. The cells correspond to pixels in image. During streamline drawing the indexes from a color table instead of colors are put into those cells. The animation effect appears after cyclical shifting in the color table. The method to compute the Motion Map proceeds as follows: computing a dense coverage of the array by a set of streamlines and streamline "coloring" by color table indexes.

The streamline "coloring" is used to create a smooth animation. For this purpose such gray scale color table is chosen that produces some intensity wave. The streamline is divided into several intervals, inside which the value of indexes in sample points of streamline runs over the color table. The length of intensity waves is increased for areas of streamlines where the magnitude of vector field is increased. So, during cyclical shifting in the color table in areas of increasing the magnitude of vector field the motion of intensity wave along streamline is accelerated.

The following equations determine the indexes as function of vector field magnitude:

$$\begin{cases} C_{\mathbf{x}_0} = random(N) \\ C_{\mathbf{x}_i} = C_{\mathbf{x}_{i-1}} + c(f(\mathbf{x}_i))N \\ I_{\mathbf{x}_i} = C_{\mathbf{x}_i} \bmod N \end{cases} . \quad (1)$$

Here $f(\mathbf{x})$ is the absolute for vector of field, N is the number of distinct colors in the color table, $\{C_{\mathbf{x}_i}\}$ is an increasing series in $\mathbf{R}^+$, $c(f(\mathbf{x}_i))$ is a linear decreasing function and $I_{\mathbf{x}_i}$ is an index from the color table. Linear function $c(f)$ that gives the increment value of index when moving along streamline is found from limit conditions:

$$c(f_{\min}) = 1/L_{\min}\ ; \quad c(f_{\max}) = c(f_{\min})R\ . \quad (2)$$

The values $L_{\min}$ and R are the visualization parameters. $L_{\min}$ is the minimum number of sample points on which a complete revolution of the color table could be mapped. This value determines the minimum length of intensity wave in final image. R is the ratio between the minimum and maximum speeds of texture movement in final animation.

The main advantage of the described method in comparison with other texture methods like popular line integral convolution method [6] consists in low computational costs. The reason for that is following. The computational costs for creating the animation sequence are almost equal the costs for calculation of single frame due to creation animation by simple cyclical shift in the color table. In fact only Motion Map is computed. The low computational costs are allowed to implement this visualization technique in software tool with interactive mode, which is necessary for the ability to change interactively the sections of 3D vector field.

2.2 Streamline constructions for arbitrary boundary

For creation of vector field texture animation by Motion Map it is necessary to use the streamline construction technique. The streamline numerical integration by fourth-order Runge-Kutta method with error estimation, step size control and cubic Hermite interpolation are suitable for most types of vector fields. Such integration technique is described in [12] and allows creating the streamlines as sequences of equidistant sample points.

However, in case application of this technique for fluid flow field visualization for water objects it is necessary to solve one additional problem of streamline construction for arbitrary, generally non-convex, boundary of vector field domain. This boundary is determined by shape of water object floor. The given problem has arisen since VisAEffect initially was developing for visualization of output data of water object mathematical model.

Taking into account an arbitrariness of boundary during proceeding of streamline integration step some situations can arise: line segment can intersect the boundary or it can be impossible to compute the next point of streamline. For resolving this problem a special algorithm was proposed [1]. Its basic idea consists in using Runge-Kutta method with lower order while the next point of curve can not be calculated and also in dividing in half the integration step size until predefined limit in case intersection of line segment with domain boundary.

Proposed algorithm was successively realized in VisAEffect for 2D case of streamline drawing in field sections. But it can be used in 3D case too.

2.3 Third component rendering

The method of flow animation by Motion Map described above is suitable for interactively visualization of 2D sections of 3D flow fields. We can display several sections simultaneously, for example getting along basic axes of Cartesian coordinates, for receiving more information about 3D field in detail. However, in order to take a good perception about 3D flow structure we must analyze a large amount of sections. In this paper a method, which makes easier perception about 3D vector field structure by 2D sections visualization, is proposed. It consists in color coding for third components of field vectors lying on section plain.

In order to represent information about the third component by color we proposed to make mapping the value α of angle between field vector and normal vector for section plain on some color palette.

It is convenient to choose a palette with color layout in following order: blue, cyan, green, yellow and red. Such color sequence is easy to implement and allows creating a good visual perception even a little change the value of angel α, because it includes all basic colors (red, blue, green). After the mapping of α values into the color palette we have an opportunity to render the vector field third component in 2D section visualization. In case of determining of vector field by the values on the regular grid the simplest approach is a sell painting by color, corresponding the angle value for vector located in center of a given sell. This approach is implemented in VisAEffect. For creating smoother visualization it can be used bilinear interpolation of colors in non-center points of sells. In such a way the 2D image of the vector field third component can be created.

Superposition of colored image of the third component and texture animation can be achieved by multiplying of color, corresponding the angle α, on texture intensity as described in [9].

The mixture of the third component rendering method and texture animation by Motion Map in one visualization allows efficient representing information about 3D vector field in intuitively way only by few 2D images of sections.

2.4 Optimized palette

The standard or linear palette (blue, cyan, green, yellow, red) is most common for visualization software environments. The word "linear" means linear variation of RGB-components. This palette has following drawbacks when it is used for colors representing on CRT displays. There exist three wide color ranges, which have hues closed to pure blue, pure green and pure red colors correspondingly. It is difficult to distinguish different colors inside those ranges. Cyan and yellow ranges quite the contrary have significantly narrow width. Moreover, inside green range hues on the left side from pure green (0,255,0) are impossible to distinguish from right side hues. This ambiguity can lead to a wrong interpretation of data structure in color coding of scalar data.

For resolving those problems we proposed the following approach. To remove ambiguity among hues in green range we proposed increasing blue component contribution for colors on the left side from pure green that makes green hues more "cold" and increasing red component for colors on the right side that makes their more "hot". For that purpose it is proposed to use parabolic variation of corresponding components. As a result in this work the optimized palette for color coding of scalar data was developed. Figure 1 shows the plot of RGB-components variation in optimized palette.

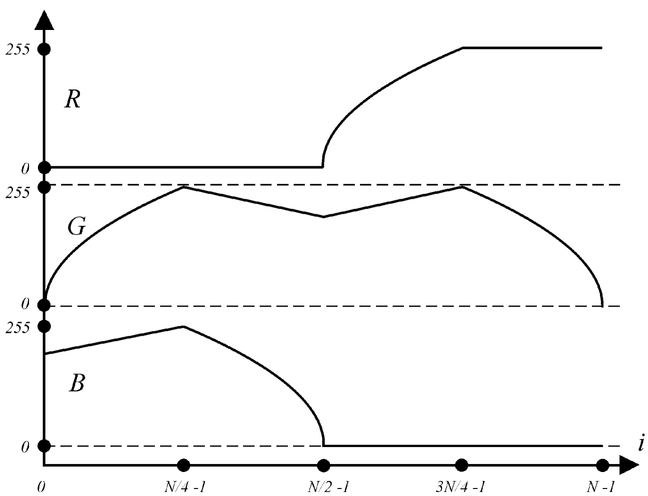

Figure 1: RGB-components in optimized palette.

Here N denotes the number of colors in palette, i is color index. The maximum number of different colors in such a palette is equal 1024. Pure blue color corresponds to index 0, cyan: $N/4-1$, pure green: $N/2-1$, yellow: $3N/4-1$, pure red: $N-1$.

In the optimized palette the ranges of blue, cyan, green, yellow and red hues have almost an equal width that assistants removing ambiguities and representing the scalar field structure in more detail.

3. SOFTWARE TOOL DESCRIPTION

This section describes the structure of VisAEffect, its basic capabilities and interface. The software tool was writing on C++ language. Its development was made by Integrated Development Environment Borland C++Builder 5. The software tool is working on Win32 platform.

3.1 Assignment

The assignment of VisAEffect is a visualization of 3D steady vector and scalar fields obtained mainly as a result of computer modeling. Initially this program was worked out with the purpose of visualization of data about water object hydrodynamic with arbitrary domain. But it can be used for analysis any kinds of fields.

3.2 Functional capabilities

The software tool allows visualizing of 2D sections of 3D vector or scalar steady fields. VisAEffect can process special format files with data organized as sequence of values of filed in nodes of 3D regular grid.

The most modern visualization software environments were developed for special graphic stations or super computers working on UNIX family operating systems. However, due to the rapid hardware evolution during the last decay the possibility to realize the most part of modern computer graphics techniques on general personal computers appeared. Therefore VisAEffect was developed for Win32 platform that gives the possibility to use this software tool for a wide range of personal computer users, which have widely spread (at least on Russian market) Windows family operating systems.

The scalar field visualization in this software tool is implemented by color coding. For that the scalar values in section points are mapped on the optimized color palette.

The software tool uses three methods for the visualization of sections of vector field. The user can simultaneously use the first two methods: arrow plot and the streamline construction method from user defined points. The arrow plot application is useful for the rapid estimation of general features of field. The third visualization method, which allows obtaining the visualization of 2D section of vector filed in detail, is the method of texture animation by Motion Map.

The texture animation along streamlines allows representing liquid or gas flow fields naturally. Figure 3 shows one frame of such texture animation. As an input data for creating of this figure the data about fluid flow field, which was obtained by system of mathematical modeling of Azov Sea hydrodynamic [4], was used. The time required for compute of animation strongly depends on streamline coverage percentage and the size of final image. For example, for creation of cyclical animation with 15 frames (Fig. 3) and size of frames 1001x679 pixels it was taken up 109 seconds (60s for Motion Map calculation and 49s for coloring of 15 frames) on personal computer: PentiumIII 450MHz, 128 Mb RAM. For the same animation with size 429x291 pixels it was taken up 33s (24s for Motion Map calculation and 9s for coloring of 15 frames).

3.3 Software tool structure

The following abstract data types were implemented in VisAEffect: 3D vector field, 3D scalar field, 2D vector field, 2D scalar field, arrow plot, streamline and Motion Map. Such type division is convenient for realization of described visualization methods. The structures of software tool parts that visualize scalar and vector fields are shown on Fig. 2. Those parts work independently. On the given figures circles denote the objects corresponding to their inscriptions, arrow and boxes denote the processes of calculation.

For vector field visualization the following processes are made. The 2D vector field corresponding to user-defined section is extracted from 3D field. Then, in case of arrow plot visualization, the 2D vector field produces arrow plot corresponding selected parameters. This plot is forwarded on visualization output. In case of streamline construction method those curves are build from the user-defined points and are forwarded on visualization output. For execution of flow animation by Motion Map method the Motion Map is computed from information about vector field in section by streamline integration and then it is used for calculation of animation sequence by cyclical shift in color table. The third component color coding is computed from information about selected section and values of 3D vectors of field in each point of it. Then the given color code merges with images of arrow plots, or streamlines, or each frame of cyclical texture animation.

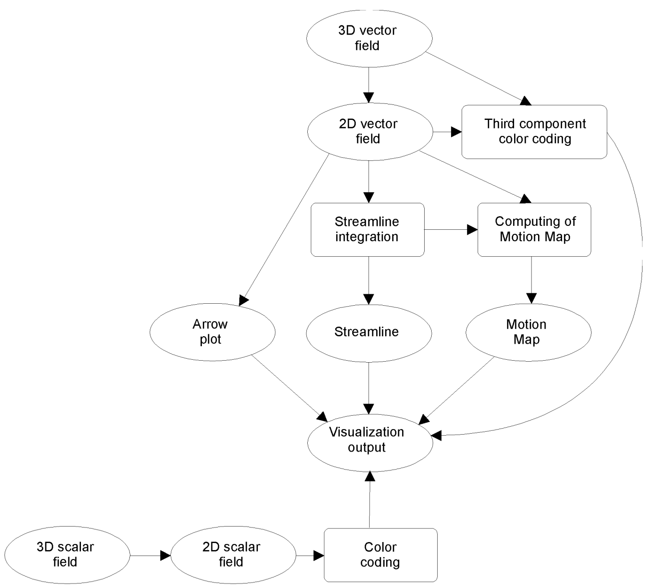

Figure 2: The structure of VisAEffect.

The scalar field visualization process is much simpler. For the given section the 2D scalar field is extracted from 3D field. Then the values of scalar field are coded by colors in other words mapped into optimized palette. The obtained color code is forwarded on visualization output.

3.4 Interface

Three subwindows of variable size, in which the visualization of three mutually perpendicular user-defined sections of scalar or vector field is possible, represent the interface of the software tool (Fig. 3). Those sections are parallel to basic planes of Cartesian coordinate system: (*xy*), (*xz*) and (*yz*). On top of the main window the image of optimized palette, which is used for color coding of scalar data and the third component of vector field, and a toolbar, which is allowed managing of visualization parameters, are located.

The software tool gives for the user two modes of vector field visualization, which are activated by main menu or speed buttons in toolbar. In the first mode the images of arrow plot merged with streamlines can be shown. In the second mode the cyclical texture animation can be made. Moreover, for both modes the third component of vector field, which is perpendicular for section plain, is represented by color that makes perception of 3D field structure much easier.

For each mode of scalar or vector field visualization the management of scale is possible by changing the size of sell (defined in pixels) for the field definition regular grid. Furthermore, the user can select interesting (*xz*) and (*yz*) sections of vector or scalar field. The selection of horizontal (*xy*) section can be made by main menu or speed button from toolbar.

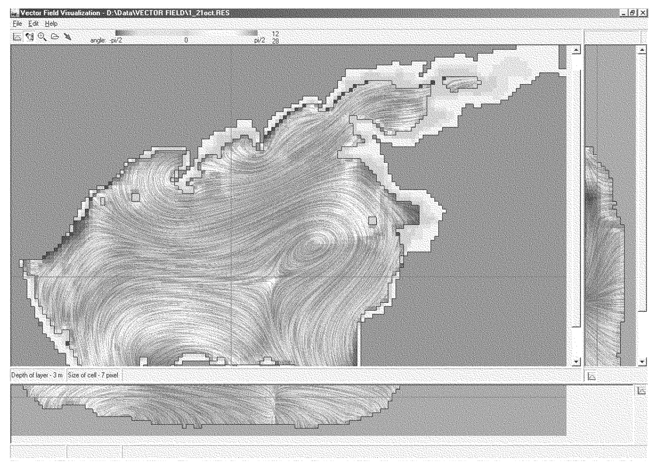

Figure 3: The frame of texture animation created by VisAEffect.

The following parameters can be changed by main menu or speed buttons from toolbar in arrow plot and streamline integration modes. For arrow plot mode: span between arrows (in number of regular grid sells), arrow enlargement factor. For streamline integration mode: initial integration step, maximum integration step, safety factor, user-defined limit of error estimate and span between equidistance sample points of streamline. The description of streamline integration parameters in detail can be found in [12].

In the mode of creation of texture animation by Motion Map besides streamline integration parameters the management of following values: coverage percentage of image by streamlines, numbers of colors in table and the minimum number of sample points L_{min}, on which a complete revolution of the color table could be mapped, is possible. The value of L_{min} has a strong influence on visualization quality. When L_{min} is small the movement of texture splats along streamline is well traced, but the shape of streamlines can be lost in chaos of splats. When the value of L_{min} as big as the length of streamlines each curve is well shaped, but the movement of texture splats disappears and animation becomes useless. Thereby the golden mean must be selected.

For scalar field visualization the two modes of image painting for data color coding exist: local, and global. In local mode for each subwindow the scalar data range from minimum until maximum value in given section is mapped into optimized palette. In global mode for all subwindows the scalar data range from minimum until maximum value in whole 3D scalar field is mapped into palette.

4. CONCLUSION

In this paper the following basic results were given. VisAEffect: the software tool for 3D steady vector and scalar field visualization was developed for Win32 platform. The 2D vector filed texture visualization method namely the flow animation by Motion Map technique, which was developed in 1997 by B. Jobard and W. Lefer, was implemented in this software tool. The realization of the given method gives the possibility for effective creation of section visualization with animation for vector field, which allows representing both global structure and detail information of field. The algorithm of streamline integration for arbitrary boundary of vector field domain was proposed and realized in software tool. The implementation of this algorithm gives an opportunity for visualization of flow fields in water objects with in general non-convex boundary defined by object floor. An approach for rendering of the third component of 3D vector field in 2D section visualization, which makes perception of 3D field structure easier, was proposed and implemented in software tool. The optimized color palette with non-linear variation of RGB-components, which allows avoiding the ambiguities and distortions in scalar data color coding, was proposed.

VisAEffect allows users to make efficient visual analysis of vector and scalar data in interactive mode and now it is used for analysis of output data for the system of mathematical model of Azov Sea hydrodynamic in South-Russian Regional Center of Informatization of High Education.

The presented in this work software tool does not have pretensions of universality because of a set of restrictions. The software tool can treat only the data located on 3D regular grid. Only steady fields can be visualized. The possibility of using the data located on irregular grids and unsteady field visualization are the areas of future researches. Besides we are planning the development of software package for 3D vector field visualization by stream surfaces and animation of textures placed on its surfaces. Such visualization method was proposed in [2].

5. REFERENCES

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