Adam PIÓRKOWSKI[1]

CONSTRUCTION OF EDUCATIONAL COLOR LAYER FOR ECHOCARDIOGRAPHY SIMULATOR

There is the educational color layer for CT2TEE, an online transesophageal echocardiography (TEE) simulator accessible at www.ct2tee.agh.edu.pl in the current paper presented. TEE is nowadays one of the most important diagnostic tools in cardiology. Because of the semi-invasive nature of this examination and complexity of heart structure the training process of learning TEE can be long and difficult, especially in patients with congenital heart disease. Therefore CT2TEE is constructed, the first online TEE simulator, described in detail in the previous publication.

This paper contains an overview on echocardiographic simulators and the previously constructed CT2TEE simulator. A detailed description of the construction and operating principles of the Educational Color Layer (ECL), an additional feature of the CT2TEE simulator, is provided. ECL, being a color information storing and indexing platform, enables to mark various 3D heart structures and facilitates the process of learning TEE.

1. ECHOCARDIOGRAPHY SIMULATORS

Echocardiography is one of the most useful diagnostic tools in the cardiology. It provides information about heart anatomy and function. The two most widespread modes of echocardiography are transthoracic (TTE) and transesophageal (TEE) echocardiography.

TTE is a noninvasive technique without known complications. The trainee learning this technique can therefore conduct this examination many times in a single patient without doing harm. TEE has a semi-invasive nature and requires the insertion of a TEE probe, being a tube of approximately 10mm diameter into the esophagus. The examination is unpleasant for the patients and can lead to complications. TEE can't be performed or repeated only for educational purposed and is therefore more difficult than TTE to learn. That's why there is place for TEE simulators, enabling to learn this important examination without doing harm to the patients. The previously developed TEE simulators are manikin based, very expensive and their use limited to only solitaire large medical centers. [1, 3-6]. The authors [2] therefore developed CT2TEE, a free online TEE simulator based on computed tomography (CT) data sets of the heart, described in detail previously [2].

2. CT2TEE SIMULATOR

The CT2TEE simulator is developed using component technology (.NET platform). It enables to create a standalone simulator application and the thin client (in Internet) version as well. The CT2TEE simulator uses a Computed Tomography data to construct a 3D model of the heart. These data are transformed to levels of brightness equivalent for TEE (Fig. 1).

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[1] Department of Geoinfomatics and Applied Computer Science, AGH University of Science and Technology, Cracow, Poland, email: pioro@agh.edu.pl
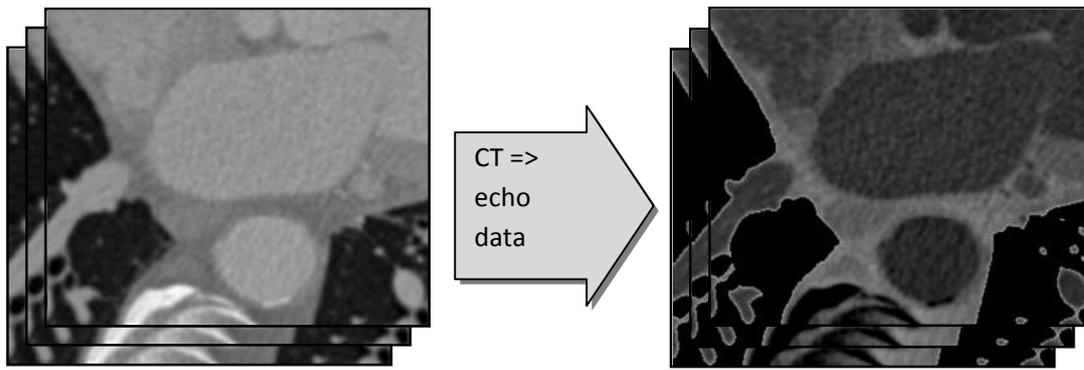
Fig.1. The data transformation used in simulation.

The examination is simulated for all parameters that define the view in the real TEE examination:
- probe depth,
- rotation angle,
- deflection angle,
- plane angulation angle,
- scan depth.

The simulator calculates a projection and simulates TEE artifacts like noise and acoustic shadow. An output is a projection of transesophageal echocardiography.

3. EDUCATIONAL COLOR LAYER

The next stage of CT2TEE simulator development is to provide an educational color layer. It should point the selected heart structures and therefore facilitate the process of learning TEE. The automated process of heart structure selecting is not available for all cases – the master of educational set should be able to highlight some defects in current input set. Therefore the authors decided to create a flexible solution, that properly realizes highlighting and is efficient in real-time picture generating. The idea of selecting heart structures is the additional block of data (Fig. 2). The data are the same data as for the simulation but the heart structures are painted by the set creator. This is proceeded in external graphical editor. The grayscale data in this block are not used in simulation.

The 3D patient model takes a big amount of data – approximately 300 MB for a set. This is a big three-dimensional matrix. The cells of matrix are *short int* type (2B) because CT data are up to 16 bits resolution. The data for color information should be stored in additional matrix. A color description takes 3 bytes (red, green, blue). In order to minimize the size of memory occupied this matrix should store the number of indexed colors only (Fig. 3). Using one byte to describe colors limits number of colors to 255. Some external editors generate shades for colors (for example to interpolate shapes and edges). The indexation process gets the pixel color values with a given precision range (*PrecisionRange*, for example 10 brightness levels for each *R*, *G* and *B* channel) to keep indexed colors number below 255. This is illustrated by pseudocode given below (where *Math.Abs* is an absolute value function). The precision range value is determined automatically (iterations from 1 to 255) during the set construction as the minimum value that keeps appropriate number of colors.

```
int ReturnIndexNumber(Pixel)
{
    for(i = 1; i < NumberOfIndexedColors; i++)
        if( Math.Abs( ColorIndex[i].R - Pixel.R ) < PrecisionRange
            && Math.Abs( ColorIndex[i].G - Pixel.G ) < PrecisionRange
            && Math.Abs( ColorIndex[i].B - Pixel.B ) < PrecisionRange
            )
            return i;
    AddToIndex(i+1, Pixel);
    NumberOfIndexedColors++;
    return i+1;
}
```

Fig. 2. The input color data for heart structures.

Fig. 3. Indexation of heart structure colors.

3.1. LOADING COLOR LAYER DATA

The loading of color data starts on user demand. First the standard set should be loaded. If user requests the color layer, a proper directory with color data is checked. The color data images are loaded into memory. During each image processing grayscale points are omitted (value 0 is the default value in color index matrix for grayscale points). Each color point is checked if its color is already indexed. If is, the indexed number is written to color matrix, otherwise a new color is put to color index and this new value is written to color matrix.

3.2. DISPLAYING IMAGES WITH COLOR LAYER

The output projection with color data is calculated by modified simulator's engine (Fig. 4) according to the formula (1). At the first a standard projection from TEE data is computed (*TeeP* matrix). This process interpolates view points. The TEE artifacts are simulated for this image. Next (or parallel) the color data projection is calculated to the matrix (*ColorP*). This projection contains only index numbers. At the last stage the TEE image is mixed with color data image (using color index table *ColorIndex*, that contains *R*, *G* and *B* values for colors). For each output pixel that has a non-grayscale color information the final value is calculated as weighted average of TEE picture and indexed color (1). The weight is given as *ratio* parameter (range 0.0 – 1.0). The final output matrix (*OutputP*) example is shown on the Fig. 5.

$$OutputP(x,y) = \begin{cases} (a,a,a), & if\ ColorP(x,y) = 0 \\ (r,g,b), & if\ ColorP(x,y) \neq 0 \\ where: \\ \quad a = TeeP(x,y), \\ \quad r = a*(1-ratio) + ColorIndex[ColorP(x,y)].R*ratio, \\ \quad g = a*(1-ratio) + ColorIndex[ColorP(x,y)].G*ratio, \\ \quad b = a*(1-ratio) + ColorIndex[ColorP(x,y)].B*ratio \end{cases} \tag{1}$$
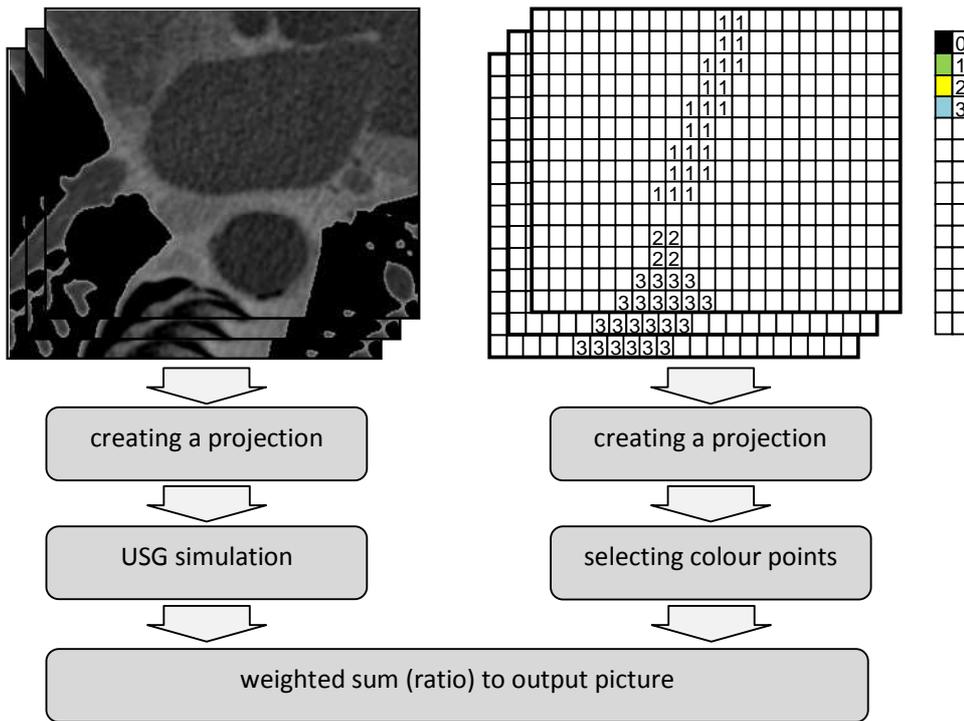
Fig. 4. Creating a projection with color data.

Fig. 5. An output example.

3.3. EFFICIENCY OF COLOR LAYER DISPLAYING

The memory usage of solution is quite satisfactory. CT2TEE simulator after start consumes 12 MB RAM, a simple testing set (7 CT images only) increases this parameter to 25MB, with educational layer memory usage is 29MB. The CPU usage is satisfactory - output image creation takes 93ms without color layer and 140ms with (Intel Core2 Duo, 2.2 GHz).

4. FUTURE WORK

The development of the project is not finalized yet. The color layer is added to the internet version of simulator (available in the Internet at: www.ct2tee.agh.edu.pl) but only for special small set – there is only 1 GB RAM in Internet server (3 sets are available). Further work will be focused on creating motion simulation in the model. The adaptation of engine and interface to simulation of transthoracic echocardiography is also possible. Although the simulator is available on the Internet since July 2009, the first official premiere took place in June 2010. Number of people interested to visit the page is still growing. The simulator authors hope that the simulation will be also useful for medical students.

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BIBLIOGRAPHY

[1] BOSE R., MATYAL R., PANZICA P., et al., Transesophageal echocardiography simulator: a new learning tool. Journal of Cardiothoracic and Vascular Anesthesia, Vol. 23, 2009, pp. 544–548.

[2] KEMPNY A., PIÓRKOWSKI A., CT2TEE – a Novel, Internet-Based Simulator of Transoesophageal Echocardiography in Congenital Heart Disease. Kardiologia polska Vol. 68, 2010, pp. 374–379.

[3] KUTTER O., SHAMS R., AND NAVAB N., Visualization and GPU-accelerated simulation of medical ultrasound from CT images. Computer Methods and Programs in Biomedicine, Vol. 94, 2009, pp. 250–266.

[4] WEIDENBACH M., DRACHSLER H., WILD F., et al., EchoComTEE - a simulator for transoesophageal echocardiography. Anaesthesia, Vol. 62, 2007, pp. 347–353.

[5] WEIDENBACH M., RAZEK V., WILD F., et al., Simulation of congenital heart defects: a novel way of training in echocardiography. Heart, Vol. 95, 2009, pp. 636–641.

[6] WEIDENBACH M., WILD F., SCHEER K., et al., Computer-based training in two-dimensional echocardiography using an echocardiography simulator. Journal of the American Society of Echocardiography, Vol. 18, 2005, pp. 362–366.