Jurnal Teknologi

Full Paper

Image-based Initial Position/Orientation Adjustment System between Real and Virtual Livers

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Article history
Received
19 June 2015
Received in revised form
26 June 2015
Accepted
10 July 2015

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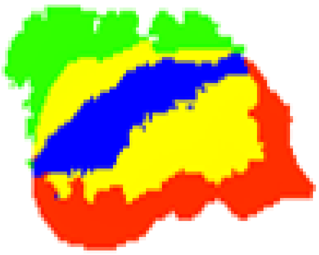
Graphical abstract



Abstract

While watching four colors, we operate a virtual liver in order to overlap its real liver. The green pixel means that a real liver exists along the depth (Z) direction, the red pixel means that a virtual liver exists along the depth (Z) direction, the yellow pixel means that they are overlapped in the XY plane, and the blue pixel means that surfaces of real and virtual livers coincident in the XYZ space. Furthermore, we compare a normal mouse and the Space Navigator (3D intuitive mouse with 6 degrees-of-freedom) for the above adjustment.

Keywords: Graphics processing unit, z-buffer, depth camera, depth image, registration

Abstrak

Semasa melihat empat warna, kita mengendalikan hati maya untuk pertindihan hati sebenar. Piksel hijau bermaksud bahawa hati sebenar wujud di sepanjang kedalaman (Z) arah, piksel merah bermaksud bahawa hati maya wujud di sepanjang kedalaman (Z) arah, piksel kuning bermaksud bahawa mereka adalah bertindih dalam satah XY, dan piksel biru bermaksud permukaan hati nyata dan maya kebetulan dalam ruang XYZ itu. Tambahan pula, kita membandingkan tetikus normal dan Angkasa Navigator (3D tetikus intuitif dengan 6 darjah kebebasan) bagi pelarasan di atas.

Kata kunci: Unit pemprosesan grafik, z-buffer, kedalaman kamera, kedalaman imej, pendaftaran

1.0 INTRODUCTION

The final purpose of this research is to construct a navigation system of liver surgical operation. Our navigation system is now designed by the following 5 functions: (1) Initial position/orientation adjustment of virtual and real livers within the display of PC in a surgical operation room, (2) Exact following a real liver by its virtual liver in the above room, (3) Exact copying a real liver cutting operation by a virtual liver cutting operation, (4) Distance calculation from a CUSA scraper to three types of blood vessels or malignant tumor, (5) CUSA control based on the two kinds of distances. [1-4]

In this paper, we propose a new support system of initial adjustment of position and orientation of virtual and real livers. Concerning to initial adjustment of position and orientation of two shapes of the same object, many types of algorithms have been already proposed.[5-10] However, almost of them should calculate combination distances of a huge number of 3D surface points representing object shape. Therefore, they are quite time consuming and then are not adequate for the real-time operation of surgical navigation.

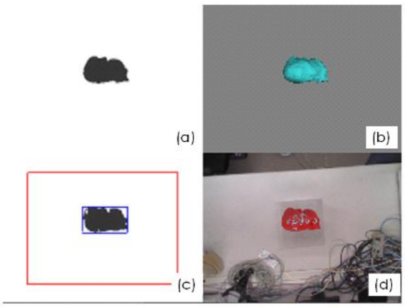


Figure 1 (a) The 2D depth image of virtual liver, (b) 3D virtual liver, (c) the 2D depth image of real liver, (d) 3D real liver.

As contrasted with this, our new algorithm compares two kinds of 2D depth images whose pixels are processing in parallel in GPU in order to follow a real liver by its virtual liver. One is to be the 2D depth image whose resolution are 320×240=76,800 pixels for capturing a real liver by the Kinect v1. The other is to be the 2D Z-buffer (depth image) for capturing a virtual liver with STL format by the GPU in PC. Based on the comparison, our algorithm can quickly search the coincidence between 3D real and virtual liver by captured and calculated 2D depth images.

2.0 CONTROL FUNCTIONS

2.1 Virtual & Real 2D Depth Image &3D Models

A liver of patient is captured as DICOM by MRI/CT, and the DICOM is converted into polyhedron with STL format (Figure 1(b)). This is used as the virtual liver in this research. Secondly, the STL is printed as the plastic real liver by a 3D printer (Figure 1(d)). This is used as the real liver in our research. In order to overlap the surfaces of 3D virtual and real livers, we use their 2D calculated and captured depth images (Figure 1(a) and 1(c)).

Figure 2 (a) Mause and SpaceNavigator, (b) Six kinds of operations of SpaceNavigator.

2.2 Operating Tools

In this research, in order to operate a virtual liver, we use a normal 2D mouse and a 3D mouse Space Navigator which has 6-degrees-of-freedom. Using Space Navigator, we choose zoom, pan left/right, pan up/down, tilt, spin, roll intuitively in 3D space (Figure 2).

* Zoom: moving a virtual liver to the Z axis (depth direction).
* Pan left / right: moving a virtual liver to the X axis.
* Pan up / down: moving a virtual liver to the Y axis.
* Tilt: A virtual liver is revolved on the X axis.
* Spin: A virtual liver is revolved on the Y axis.
* Roll: A virtual liver is revolved on the Z axis.

2.3 Many Control Items

Our system can be controlled by the display of PC in a surgical operation room (Figure 3). In the display, we firstly choose the view point of depth camera Kinect v1 (Figure 4), and secondly choose XY region

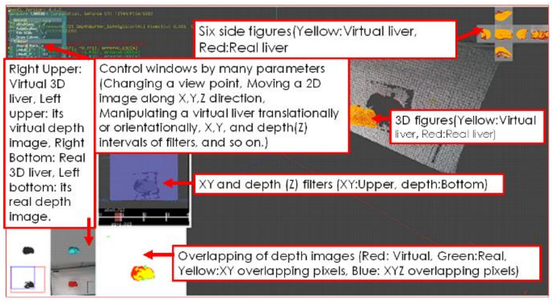


Figure 3 Main display with control windows, 3D figures, a set of six side figures, XY and depth filters, two real and virtual liver images and their 2D real and virtual depth images, overlapping 3D real and virtual liver displayed by red, green, yellow, and blue.

and Z (depth) interval captured by the depth camera (Figure 5). Furthermore in order to choose the region and interval precisely, we use a numerical window (Figure 6) for choosing coordinates for adequately XY region and Z (depth) interval including a real liver in a surgical operation room.

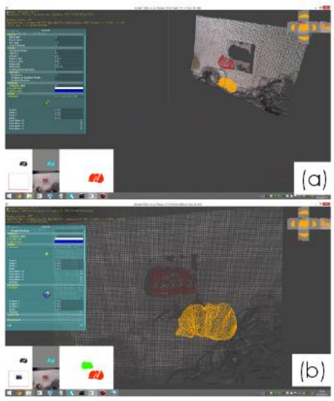


Figure 4 (a) Main display before adjusting view point (position/orientation) of depth camera by a human. (b) That after adjusting view point of depth camera by human.

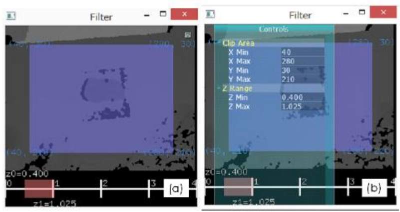


Figure 5 (a) Upper: a captured region selected within XY-plane, Bottom: a captured interval selected along Z-axis (depth direction), (b) their region and inverval modified by numerical version.

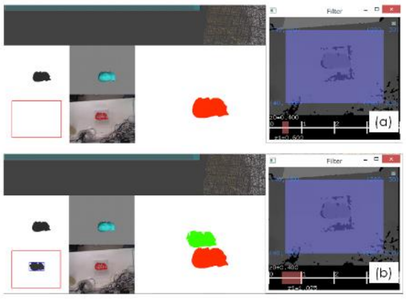


Figure 6 (a) Before adjusting XY and depth(Z) filters, only the virtual depth image appear. (b) After adjusting XY and depth(Z) filters, virtual and real depth images appears.

3.0 FILTER PROCESSING

As mentioned briefly, we should choose XY region and Z interval for detecting a real liver in a 3D real environment by Kinect v1. For this purpose, we successively do the following procedures:

1. In Figure 5(a), if a bar of the lower part is roughly controlled by a human (a medical doctor), a captured region of a real liver in Kinect v1 can be set as the z axial direction. (In succession, numerical value input will be available in Z range by control indicators described in Figure 5(b).)

2. In Figure 5(a), if a human (a medical doctor) controls the part where the upper region is applied in blue, a real liver can be captured in the blue region of the XY-plane. (The numerical X and Y coordinates can be selected for the XY region in another window menus shown in Figure 5(b))

3. When filter setting is finished, a 2D depth image of a 3D real liver can be ascertained in Figure 6.

Figure 7 (a) Control box (General, Tracker, Modulator, Diff-image, Viewer), (b) Control box continued (Manipulator, Color-Finder, Kinect-Sensor and so on.).

4.0 INITIAL ADJUSTMENT

First, we use a 2D normal mouse and then a 3D pointing device Space Navigator in order to overlap a virtual liver with a real liver in a 3D surgical operation room (Figure 7).

4.1 Basic Processing

Viewer

* Direction: We can change a central arrow by the left drug and change a viewpoint roughly.
* Pivot X: X axis movement of a screen.
* Pivot Y: Y axis movement of a screen.
* Pivot Z: Z axis movement of a screen.
* Zoom: Zooming for the screen.
* Pane Move +X: X + makes the numerical value of the axial direction by only a certain quantity.
* Pane Move -X: X -makes the numerical value of the axial direction by only a certain quantity.
* Pane Move +Y: Y + makes the numerical value of the axial direction by only a certain quantity.
* Pane Move -Y: Y -makes the numerical value of the axial direction by only a certain quantity.
* Initialize: Return to the initial condition.

Manipulator

* Rotation: Revolve a virtual liver.
* Position X: X axis movement of a virtual liver.
* Position Y: Y axis movement of a virtual liver.
* Position Z: Z axis movement of a virtual liver.
* Zoom: The virtual liver size is expanded/reduced.
* Initialize: Return to the initial condition.

4.2 Adjustment Flow

A virtual liver, a series of flow until an adjustment with a liver model is as follows.

1. By changing the direction arrow in the viewer, the viewpoint is flexibly changed (If necessary, we use the Zoom item to enlarge a virtual liver where we can see easily).

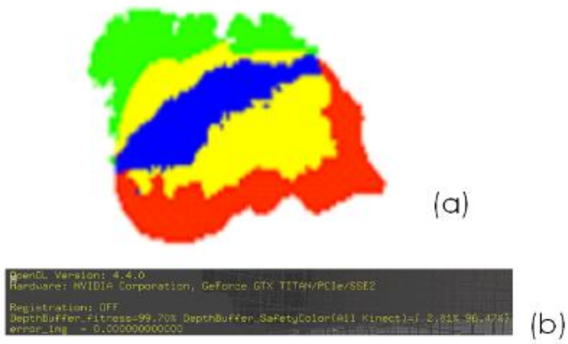


Figure 8 (a) A depth virtual liver is illustrated by red, and another depth real liver is illustrated by green. Furthermore, exact overlapping real and virtual livers in the XY-plane is illustrated by yellow, and that in XYZ-space is illustrated by blue. (b) Overlapping ratio (the number of blue pixels)/(the number of red pixels) * 100 is always indicated by the percentage.

2. While watching the window described in Figure 8(a), a virtual liver is controlled by a 2D normal mouse and a 3D mouse Space Navigator. At each pixel, a virtual liver is represented by red, and another real liver is represented by green, overlapping real and virtual livers in the XY-plane is represented by yellow, and that in XYZ-space is represented byblue (Figure 9). Finally, we also indicate the overlapping ratio (the number of blue pixels) / (the number of red pixels) * 100 as the percentage in the window shown in Figure 8(b).

Table 1 The developer overlaps a virtual liver with its real one in our system.

Developer	Mouse	Space Navigator
Time (minute)	2:23	1:26
Accuracy (%)	85	95

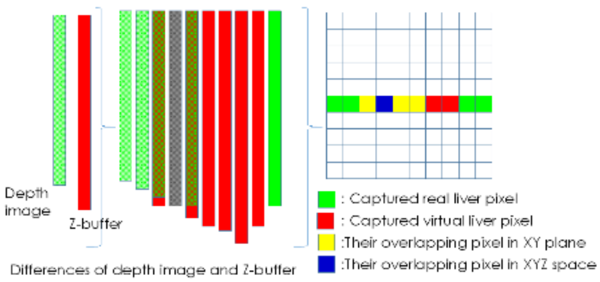


Figure 9 Difference color image between real and virtual depth images whose pixels are calculated in parallel based on Z-buffer of GPU.

Table 2 Several users overlap a virtual liver with its real one in our system within 3 minutes.

User	Mouse	SN before training	SN after training
A	63%	72%	85%
B	71%	46%	72%
C	55%	62%	92%
D	67%	59%	94%

5.0 EXPERIMENTAL RESULTS

In this section, we describe operation time and coincident accuracy in the high-experiment developer and several general users. For this purpose, we prepare a sequence of operations for overlapping a virtual liver with its corresponding real liver as shown in Figure 10. Then, this operation sequence is continued until the overlapping ratio become high enough. This trial is achieved by the developer of this system as an expert, and successively is individually achieved by four beginners. The speed and accuracy of their operations are indicated in Tables 1 and 2.

As shown in the Table 1, the developer with a lot of experiments uses a normal 2D mouse and a 3D mouse Space Navigator, and consequently he quickly overlaps surfaces of 3D real and virtual livers with high accuracy. Therefore, if a person with many experiences operates such a task, 3D mouse is better than 2D mouse concerning to speed and precision. In Table 2, several persons without any experiment of Space Navigator achieve the same task. Initially, some of them are wondering the intuitive 3D mouse Space Navigator. However after they got many experiences of Space Navigator, almost all persons achieve the same task more fast and precise.

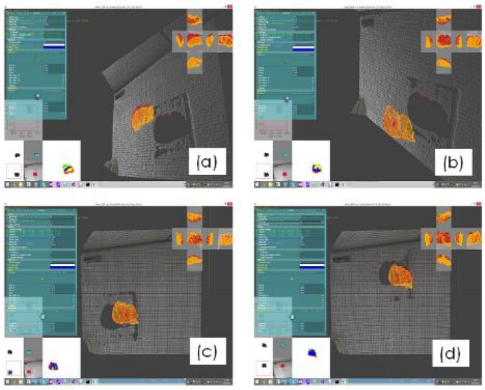


Figure 10 A strobe sequence of adjustment operations for virtual and real 3D livers by matching 2D depth images of virtual and real livers.

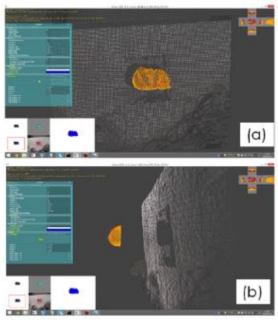


Figure 11. Final adjustment stage of virtual and real 3D livers by matching 2D depth images of 3D virtual and real livers. Virtual depth image represented by red and real depth image represented by green disappear, and consequently blue depth image appears. (a) Top view. (b) Side view.

6.0 CONCLUSIONS

In this paper, we proposed a smart initial position/orientation adjustment system. The system is used by matching depth-depth images in GPU. By using parallel processing of GPU, the matching based on four color control is quite fast. In addition, in order for a human (a doctor) to overlap surfaces of real and virtual livers easily, we tested the 3D pointing device Space Navigator. It is better than a normal 2D mouse after a human (a doctor) got many kinds of 3D operation experiments.

Acknowledgement

This is supported in part by 2014 Grants-in-aid for Scientific Research (No. 26289069) from the Ministry of Education, Culture, Sports, Science and Technology, Japan. Also, this is supported in part by 2014 Collaborative Research Fund for Graduate Schools (A) in Osaka Electro-Communication University.

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