A hyperelastic-boundary-element based surgical-simulator for training surgeons in a few eye-hand-coordination tasks related to minimally invasive surgery

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ABSTRACT

The present invention relates to a surgical simulator that may be used to train surgeons in a few tasks related to minimally invasive surgery. To be specific, the simulator can be used to train surgeons in the following tasks: eye-hand coordination, poking the computer model of a liver or a kidney on a computer screen while the deformation is observed on the screen. The simulator makes use of hyperelastic boundary-elements. Moreover, the simulator makes use of the hyperelastic boundary-element-codes developed by this inventor. The simulator consists of a computer screen, a keyboard, a mouse, and a multi-core CPU. The mouse pointer (on the computer screen) represents the tip of a surgical tool. The simulator would include the three-dimensional geometry (3D computer model) of representative human kidney and human liver. The simulator has provisions for detecting the collision between the 3D model of the liver or the kidney on the screen and the mouse pointer (tip of the surgical tool) on the screen. In addition, the simulator has provisions for interactively displaying the deformed shape of the liver or the kidney on the screen, depending on the position of the mouse pointer (tip of the surgical tool) on the screen. This patent application uses many sentences from the same inventor's another invention titled "A surgical simulator

for training surgeons in a few tasks related to minimally invasive surgery" (Indian patent application number: 201641031739, date of filing: September 17, 2016). However, the two inventions are based on two different technologies; the present invention is based on hyperelastic boundary-elements whereas the earlier invention is based on linear elastostatic boundary-elements. Moreover, the two inventions are two different and independent products. Neither of the inventions may be thought to be an improvement of the other. Of course, although they are two different products, they cater to the same customer group. Which of the two products is going to be more successful depends on whether the customer prefers the present invention or the previous invention; after selling sufficient number of products one can know which of the products is more successful. At least, extensive testing/validation is required before one can know which of the inventions is the better product.

TECHNICAL FIELD

The present invention relates to a surgical simulator that can be used to train surgeons in the following skills that are related to minimally invasive surgeries: eye-hand coordination, poking the computer model of a liver or a kidney on a computer screen while the deformation is observed on the screen.

BACKGROUND

Just as flight simulators are be used to train pilots, surgical simulators are used to train surgeons in some surgical procedures (e.g., eye-hand coordination, manipulating 3D objects or organs using surgical tools, palpation). The main application of surgical simulators is to train surgeons for minimally invasive surgery (e.g., laparoscopic surgery).

This inventor's earlier invention [1] is a surgical simulator that is based on linear elastostatic boundary-elements.

A careful review of prior art indicates that no surgical simulator that makes use of hyperelastic boundary-elements is disclosed so far. Further, no hyperelastic boundary-element code is available as open-source software. Moreover, none of the proprietary software packages (closed source) use hyperelastic boundary-elements.

The present invention is based on hyperelastic boundary-elements. The hyperelastic boundary-element codes are developed from scratch by the present inventor himself.

To contrast the present invention with this inventor's earlier invention [1], the present invention is based on hyperelastic boundary-elements whereas the earlier invention [1] is based on linear elastostatic boundary-elements. Moreover, the two inventions are two different and independent products. Neither of the inventions may be thought to be an improvement of the other. Of course, although they are two different products, they cater to the same customer group. Which of the two products is going to be more successful depends on whether the customer prefers the present invention or the previous invention; after selling sufficient number of products one can know which of the products is more successful. At least, extensive testing/validation is required before one can know which of the inventions is the better product.

SUMMARY

The present invention is about a surgical simulator that may be used to train surgeons in some tasks related to minimally invasive surgery.

This inventor's earlier invention [1] is a surgical simulator that is based on linear elastostatic boundary-elements whereas the present invention is based on hyperelastic boundary-elements. The hyperelastic boundary-element codes used in the present simulator are developed from scratch by the present inventor. One may note that prior-art search does not show up any surgical simulator that makes use of hyperelastic boundary-elements. Further, no hyperelastic boundary-element code is available as open-source software. Even the proprietary software packages (closed source) have not incorporated hyperelastic boundary-elements.

The present simulator can be used to train surgeons in the following tasks: eye-hand coordination, poking the computer model of a liver or a kidney on a computer screen while the deformation is observed on the screen.

DETAILED DESCRIPTION OF THE PRODUCT

In this section, hardware and software are specified first. The specification of the product (invention) is clearly mentioned afterwards. The user interface of the product (invention) is explained next. A short discussion on validating the product is presented later. Novelty, inventive step, and commercial applications of the invention are clearly highlighted at the end of the present section (i.e., Detailed description of the product).

Hardware

Screen: Ultra-wide LED monitor
Keyboard: Standard keyboard
Mouse: Optical three-button mouse (with scroll wheel)
CPU: Intel Xeon E7 v4 (24 cores), mounted on a motherboard with sufficient RAM

Software

Operating system: Windows 10
Other software: hyperelastic boundary-element codes developed by this inventor, C++ libraries used for 3D rendering and collision detection (free and open-source libraries are used)
Files: STL (stereolithography) files which represent the geometry of representative human kidney and human liver

Specifications of the product

The hardware mentioned above plus the software mentioned above, together with some additional software that is used to bind together all the other software to form the user interface, make up the new product. The specifications of the additional software (user interface) are presented in the next subsection titled "User interface". Of course, the individual elements (i.e., hardware, software, user interface) of the product, if considered alone, may not possess enough of novelty and/or enough of inventive steps. However, when all the elements (i.e., hardware, software, user interface) are put together to form a product, the product (invention) is found to possess sufficient novelty, the invention is found to involve inventive step that is significant, and the product is found to have useful and important commercial applications. The product (invention) may be used to train surgeons in the following tasks: eye-hand coordination, poking the computer model of a liver or a kidney on a computer screen while the deformation is observed on the screen.

User interface

Geometry of either a representative human kidney or a representative human liver is displayed on the screen (monitor), through the rendering capabilities offered by the C++ libraries. The position of the mouse cursor on the screen is sensed by the C++ libraries (3D position can be sensed, although the screen is 2D). The mouse cursor itself represents the surgical tool (or the tip of the surgical tool). The C++ libraries check whether the mouse cursor lies inside the undeformed geometry or whether the mouse cursor lies outside the undeformed geometry. In case the mouse cursor is found to lie inside the undeformed geometry, the geometry of the biological organ is substituted with the deformed geometry such that the mouse cursor would lie on the surface of the deformed geometry. The deformed geometry is displayed through the rendering capabilities offered by the C++ libraries. This cycle continues throughout the use of the simulator. The total number of the cycles is about thirty per second, resulting in real-time graphics on the screen.

During the cycles described above, the deformed geometry is obtained from the undeformed geometry by making use of the present inventor's hyperelastic boundary-element codes. The codes used are fully parallelized so that they run very fast on the multi-core computing system used. To speed up the computations further, the geometry of the liver and the kidney used is a crude approximation of the true geometry, and a coarse meshing is employed. With the focus on speed, accuracy is sacrificed to some extent by explicitly allowing some amount of error in the solutions, by specifying lower convergence requirements in the (nonlinear) solver also.

Validation

The only reliable way of measuring the performance of a surgical simulator is to obtain the feedback on the simulator from many surgeons. The feedback can be collected once the device (simulator) is marketed.

Novelty

1. A surgical simulator that is based on hyperelastic boundary-elements.
2. A surgical simulator that is based on the hyperelastic boundary-element codes developed by this inventor.

Inventive step

1. While the previous invention by the same inventor uses linear elastostatic boundary-elements, the present invention uses hyperelastic boundary-elements.
2. The present simulator makes use of the hyperelastic boundary-element codes developed by this inventor, not the boundary element codes developed by someone else. One may also note that no hyperelastic boundary-element code is available as of now as open-source software (either developed by this inventor or someone else). And none of the proprietary software packages (closed source) have incorporated hyperelastic boundary-elements.

Commercial applications

1. The simulator may be used to train surgeons in the following tasks: eye-hand coordination, poking the computer model of a liver or a kidney on a computer screen while the deformation is observed on the screen.

2. The new simulator could be an alternative to the simulator previously invented by this inventor [1]. The simulator disclosed in [1] is faster whereas the present simulator provides more accurate deformation of the liver/kidney on the computer screen. Since the realism offered by a simulator depends both on the speed of the internal computations as well as how accurate those computations are, it is difficult to decisively say which of the two simulators provides more realistic simulations. However, both the simulators are most likely to provide better realism when compared to some simulators in the market that are not based on continuum mechanics (since the literature is already clear that simulators that are based on continuum mechanics are superior).
3. The literature tells that the behaviour of biological organs like liver and kidney is closer to hyperelasticity than to linear elastostatics. Naturally, it is reasonable for anyone – including customers – to prefer a simulator that is based on hyperelasticity over a simulator that is based on linear elastostatics.

CLAIMS

1. A simulator that may be used to train surgeons in the following tasks is developed: eye-hand coordination, poking the computer model of a liver or a kidney on a computer screen while the deformation is observed on the screen.
2. The simulator makes use of hyperelastic boundary-elements.
3. The simulator makes use of the hyperelastic boundary-element codes developed by the inventor.
4. The simulator consists of a computer screen, a keyboard, a mouse, and a multi-core CPU. The multi-core processor has 24 cores (Intel Xeon E7 v4).
5. The simulator would include the geometry of representative human kidney and human liver.
6. The simulator has provisions for detecting the collision between the 3D model of the liver or the kidney on the screen and the mouse pointer (the mouse pointer represents the tip of the surgical tool) on the screen. In addition, the simulator has provisions for interactively displaying the deformed shape of the liver or the

kidney on the screen, depending on the position of the mouse pointer (tip of the surgical tool) on the screen.

7. The codes used (mentioned in 3. above) are fully parallelized codes, so that they run very fast on the multi-core computing system used.

8. To speed up the computations further, the geometry of the liver and the kidney used is a crude approximation of the true geometry.

9. A coarse meshing is employed with the intention of obtaining the solutions faster.

10. With the focus on speed, accuracy is sacrificed to some extent by explicitly allowing some amount of error in the solutions, by specifying lower convergence requirements in the (nonlinear) solver also.

REFERENCES

[1] Kirana Kumara P, 2016, "A surgical simulator for training surgeons in a few tasks related to minimally invasive surgery," application number (Indian patent): 201641031739, filing date: September 17, 2016, date of publication: September 30, 2016, journal number: 41/2016