IB EXTENDED ESSAY

Computer Science

Use of Augmented Reality alongside Neural Networks in the Field of Brain Surgery

Session : May 2019

Candidate Number : 000480-0004

Word Count : 3999

Supervisor: Mr. Anthony

Date : 2019-02-15

Table of Contents

1. Introduction

Technology often gives an easier method to approach difficult problems and offer a means to solve them. The various forms of technology that we use today—ranging from the graphing calculators in our pencil cases to the laptops and phones that we carry on us—are now able to solve complex calculations and mimic a lot of aspects in our real world to facilitate a better understanding of these problems. Due to this, programmers and computer scientists aim to improve the ability of these machines such that they can complete these various subtasks of a problem within a smaller time frame. In time, computer scientists will have created computers capable of completing human processes through the use of various neural networks—mathematical models used to encapsulate the functions of the neural circuit network of the human brain. The first step to improving this technology is to first understand how exactly the brain works.

1.1 The Importance of the Brain

All animals in our world are able to process information and respond to their environment based on the information taken from their senses. This is due to a single organ which works in tandem with every other organ by sending out nerve signals to make them operate accordingly—the brain. The brain is considered to be the mass of nerve tissue located in the head of an organism. It is able to integrate sensory information and motor responses via electrical impulses sent through the nerves connected throughout our body. The unique characteristic of human brains compared to those of other animals is the development of the forebrain. The forebrain contains the cerebral hemispheres; various sections of the brain which control higher levels of thinking and refined motor skills, as well as different feelings and senses including hunger, pain, and lust. Within the forebrain exists the primate cortex, which is more often called the frontal lobe. It has no dedicated duty, rather it focuses on higher mental activities such as thinking and understanding complex information.[1] This is why brain surgeons are revered as highly important individuals. They hold the key to healing

[1] Britannica, The Editors of Encyclopaedia. "Brain." Encyclopædia Britannica, Encyclopædia Britannica, Inc., 9 Oct. 2018, www.britannica.com/science/brain.

the one part of the body which sets humans apart from other organisms. Due to the uniqueness of the human brain, it is regarded as the most important organ within the human body.

1.2 Introduction to Augmented Reality

Augmented reality is the superimposition of a computer-generated image over the real-world, creating a combined and composite view.[2] This composite view is created via programs created by computer scientists. These programs can do a certain procedure known as visualization. Visualisation is the representation of data in ways that make them more perceptible, engaging the human sensory system directly. Within visualization exist 3 stages : selective emphasis, transformation, and contextualization. Selective emphasis focuses on the detection of hidden patterns by highlighting certain features while suppressing others. Transformation involves manipulating the nonvisual data such that it can become a visual image through the mapping of its values into visual characteristics. Finally, contextualization provides a visual context, or framework, where the data can be displayed.[2] Through these 3 methods, scientists are able to visualize complex data and manipulate them in a simpler fashion. A system starts to become an augmented reality when it exhibits a closer interaction between the expanded range of data input with a broader range of feedback options. Augmented reality facilitates an easier understanding of data as it acts as a form of visualization for the user, thus making complex tasks much simpler and achievable.

1.3 Introduction to Neural Networks

The most basic processing format for a computer is through the use of binary notation. Millions of binary gates hidden within the arithmetic logic unit (ALU) of the central processing unit (CPU) function together to accomplish simple tasks in a language understood by the computer.[3] What happens if the computer was given the task of analyzing

---

[2] Wexelblat, Alan. Virtual Reality: Applications and Explorations. Academic Press, 1995.
[3] Pimental, Ken and Texeira, Kevin. Virtual Reality : Through the new looking glass. McGraw Hill. May 30, 1994.

a handwritten number? Try as the programmer might, the program will ultimately always fail using this system as the computer would simply run out of storage accounting for every unique form of writing a number. This is where neural networks come in to simplify the task. A neural network—more properly referred to as an 'Artificial Neural Network' (ANN)—is a processing device loosely modelled after the neuronal structure of the human brain. It is a system of highly interconnected processing elements that change according to their dynamic state response to external input. Each individual element records the external input, and based upon both the weight factor and the decision making gate, evaluates its state of activation.[4] To look back on the handwritten number example, a neural network would have a sample dataset of size *x* and using that dataset, would attempt to analyze the handwritten number, making comparisons to the dataset. These comparisons are based on various weight factors which were created according to the relevancy of the data to the task. These comparisons are carried out through logic gates, aiding the computer to identify the number. Not only will it more accurately identify the handwritten number, but it will also keep a record of the newfound data, and ameliorate it with the old data, updating the weight factors as necessary. This will increase the efficiency and effectiveness of the program, allowing it to recognize handwritten numbers much more quickly. Neural networks aim to simplify complex computational tasks.

1.4 The Research Question

A combination of neural networks alongside augmented reality can help facilitate an easier understanding of the surgical model. Due to the implicitly difficult nature of a surgery, surgeons are often required to have extremely fine motor control, and be able to stay calm under the pressure. However, the various improvements to technology have opened the door to different methods and possibilities in the medical field. Using augmented reality helps to decrease the complexity of surgery by allowing the surgeon a hands-on manipulation of the data. This task can be further simplified using neural networks that learn about the procedure

[4] "A Basic Introduction to Neural Networks." *History of Cajun Country*, pages.cs.wisc.edu/~bolo/shipyard/neural/local.html.

as it is being conducted. This would allow the program to offer suggestions and give practical aid in the midst of a surgery. This brings about the following question : how can we use a combination of augmented reality with neural networks to facilitate easier and more accessible brain operations for all surgeons? This essay aims to explore the compatibility of augmented reality in the surgical room and see whether it can be utilized to simplify the procedure of brain surgery.

2. Current State of Surgery

Since the brain is such a delicate and integral organ for humans, there are not many medical procedures which can be done to easily fix it. It is also one of the few organs of the human body which has no record of being transplanted due to the archaic connections between the nervous system and the brain. For this reason, patients of brain tumours and other neurological diseases were seen as doomed until the discovery of gamma knife radiosurgery.

2.1 Gamma Knife Radiosurgery

Gamma knife radiosurgery is a form of radiation therapy—a surgical treatment which involves the use of intense beams containing certain radioactive particles to treat certain parts of the brain. In the case of the gamma knife, a beam of gamma rays are focussed on a particular part of the brain to deal with lesions, cancer growth, or tumours, often requiring pinpoint accuracy.[5] Contrary to what the name suggests, there is no actual knife being used, however it is similar to scalping off the damaged parts of the organ using a knife. It is particularly effective in treating tumours as it aims to destroy the DNA of the tumour cells, preventing it from reproducing. This will allow the brain tumour to shrink over time until it finally disappears. However, there does exist some issues with this procedure.

---

[5] "Gamma Knife Radiosurgery - The Most Effective Treatments at Columbia Neurosurgery." Columbia Neurosurgery, www.columbianeurosurgery.org/treatments/gamma-knife-radiosurgery/.

2.2 Current Issues with the Procedure

The biggest issue with this procedure is the necessity for pinpoint accuracy when firing the gamma rays into the brain. Since the brain is a collection of cells that often cannot regrow after a certain age, destroying healthy brain cells would result in varying degrees of issues for the patient.[6] This is why there has been a large focus on improving the accuracy of both the machine and the program used in the machine. Computer scientists have been improving the software in these machines so that surgeons can fire the beams into the brain with much more accuracy. However, this still relies on the surgeon being precise with their aim and ensuring that they have properly recognized both the type of issue and the location of the tumour in the brain. The software is still reliant on the user, and is not self-sufficient. These would be the next stage of improvements for gamma knife radiosurgery machines. This is where the evolution of technology becomes crucial.

3. Current State of Technology

Technology has evolved throughout the years to virtualize and simplify many of the everyday tasks that humans face. Originally, data from a computer could be viewed only as binary notation, where the placements of 0s and 1s determined whether a calculation was done correctly. This format changed and become what we now call GUI—a graphical user interface. A GUI visualizes the data using images and other variations of graphics to portray the data in a much more understandable manner.[7] A prime example of a graphical user interface is the homescreen seen on each and every laptop. However, limitations in understanding still exist within this format, so computer scientists created another method to represent this data : through virtual and augmented reality. As mentioned earlier, augmented reality involves the superimposition of an image over the real world to facilitate an easier understanding of the data. The early examples of augmented reality were able to create simple dimensions that contained one or more three-dimensional images that the user can

[6] "Gamma Knife Surgery, Advantages and Disadvantages of Gamma Knife." The Gamma Knife, 25 Apr. 2017, www.thegammaknife.com/advantages-disadvantages-gamma-knife/.

[7] Azuma, Ronald, et al. "Recent Advances in Augmented Reality." *IEEE*, Nov. 2001.

maneuver and observe. Over the past few decades, augmented reality has evolved and is now an integral part of our society.

3.1 Augmented Reality in Society

Augmented reality is now used in most gaming systems, such as the Oculus Rift or the PS VR system, to create a more immersive gaming experience for the user. It has also found its way in the sports industry as many sports analysts use a form of augmented reality to indicate various tactical plays and/or highlight certain players during a play-by-play of a match.[8] One example is in soccer where analysts highlight certain players on the screen and trace their paths throughout the game, superimposing images and drawings onto the play-by-play recording. More recently, augmented reality has found its way into the modern smartphone as multiple apps started using its capabilities for both commercial and educational purposes.[8] One commercial app is IKEA Place, which allows IKEA customers to place their IKEA furniture in their own room with the click of a button. By scanning the desired room, the phone is able to render a three-dimensional image of the room onto the screen where it can then superimpose the various furniture on top of the image, taking into account the dimensions of the room itself using a form of depth perception.[9] Even more recently, however, computer scientists were able to bring augmented reality into the surgery room to aid the surgeons with their various operations.

3.2 Early Application of Augmented Reality to Surgery

Augmented reality allows surgeons to view the surgical field through the superimposed three-dimensional virtual model of anatomical details. For this to happen, surgeons would need an AR device; an augmented reality device comprised of a computational unit with a rendering model engine, a display unit, and a tracker unit. The

---

[8] Maung, Pye P. "Augmented Reality Using a Neural Network." *Department of Mathematics and Computer Science*, *Ripon College*, 9 Mar. 2012.

[9] "IKEA Place Augmented Reality App." *IKEA Highlights 2017*, 2017, highlights.ikea.com/2017/ikea-place/.

computational unit processes the information and creates an image using the rendering model engine. The display unit is where this model is portrayed, and the data is originally collected using the tracker unit. This means that for an AR-based surgical system, patient-specific three-dimensional models (CT scans or MRIs) are superimposed on the real views of the surgical field.[10] The surgeon, looking at a display unit, views the overlay on the organ and makes the necessary incisions according to the image. This view provides surgeons with improved visualization of the anatomical structure. It also provides access to radiological images and allows for surgical planning contextually to the real patient anatomy. For image-guided surgery (IGS) systems, augmented reality integrates surgical navigation with virtual planning alongside the patient's anatomical details. However, there does exist some issues with this system. There are often issues with the actual superimposition of the image as it sometimes does not register alongside the body. There also exists some manipulation issues as only one surgeon is able to manipulate the data at a time, often making operations involving a team of surgeons much more difficult.[10] There may not seem to be any actual equipment improvements which could be done soon, however there are other things which would make the process much easier. One method would be through the introduction of a neural network.

4. The Start of an Autonomous Era

Although technology has improved greatly over the past few decades, there still exists many issues regarding user-data manipulation and human error. There is no way to improve computational technology that would allow for a decrease in human error. However, there is another way to prevent these errors from occurring entirely; remove the initial problem via neural networks. There are seven categories of tasks which a neural network can do better than a traditional computational tool : pattern classification, cluster formation, function approximation, forecasting of data, optimization of systems, association of data networks,

[10] Pimental, Ken and Texeira, Kevin. Virtual Reality : Through the new looking glass. McGraw Hill. May 30, 1994.

and control of networks.[11] Neural networks offer the solution to data manipulation and management while ensuring both the safety and legitimacy of information. After years of research, neural networks have now found a way into both the workforce and our daily lives.

4.1 Neural Networks in Society

There are multiple Artificial Neural Network (ANN) applications being used in microbiology for the analysis of various microorganisms for their identification. One such example is in the analysis of pyrolysis mass spectra for microorganism identification and analysis of food system. After being tested, results show that ANNs are much faster, more accurate, and more cost effective when compared to traditional techniques. Many applications of neural networks involve analysing growth patterns, and creating predictive graphs (forecasting) the information of expiry dates or growth rates.[11] The reason why ANNs are better for modelling growth curves is due to their ability to include all operating parameters in a single model. This form of data manipulation is near impossible for traditional computation tools as it would require the creation of a complex mathematical formulae to represent the output before the data could be processed. This technology can be further used to improve augmented reality systems.

4.2 Improvements to Augmented Reality

The two basic components of an augmented reality system are the vision recognition system and the three-dimensional rendering engine. The main goal of this system is to incorporate virtual elements with real elements. This vision recognition system was originally based upon a computational analysis of a coordinate plane that reconstructs the scenario within itself before applying the virtual elements.[12] However, this part of the augmented reality system can be improved through the use of a neural network. Instead of basing the vision recognition system off of a computational analysis, the system can mimic

---

[11] Basheer, I A, and M Hajmeer. "Artificial Neural Networks: Fundamentals, Computing, Design, and Application." *Journal of Microbiological Methods*, vol. 43, 2000, pp. 3–31.

[12] Westwood, James D et al. Medicine Meets Virtual Reality 2000. IOS Press, 2000.

the behaviour of the human vision recognition system. The neural network would be able to use pattern recognition from prior data to more quickly analyze and construct a three-dimensional render of the field. Our brain divides the visual scene into sub-dimensions, such as colour, movement, form, and depth, before merging them all together to form the perceived image. This process is similar to the algorithmic approach of 'Divide and Conquer' as a problem is divided into simpler subproblems, solved individually, then merged together. Since there is already an algorithm for this subtask, the only issue becomes prior knowledge. A recursive function could only go so far before collapsing due to the amount of data given. A neural network simply processes a set of 100 000 samples before analyzing the field, improving its accuracy and 'vision' with each new analysis and reconstruction.[11] Through this method, neural networks have already seen minor incorporations into augmented reality systems. Neural networks have also seen newfound integration within the medical field.

4.3 Early Implementations within the Medical Field

Although neural networks are mainly known for pattern recognitions and forecasting of data—hence why it is used both in economics and microbiology—it can also serve to accomplish certain visualization tasks done by humans. These includes visualizations of human anatomical models on MRIs and CT scans to properly identify the issue with an organ. One such recent example of this is the brain tumor segmentation method derived using Deep Neural Networks (DNNs). The DNN system was given sample MR images of glioblastomas, both in high and low resolution, and then based on that information, constructed a segmentation schematic for properly removing the tumour from the brain. The system did this by first analyzing the MR image, then construction a layered two-dimensional stack of images containing each layer of the brain.[13] After that, the program segmented off each and every individual two-dimensional image, showing the necessary incisions to be made for that particular section. Finally, the system combined all the images to form a three-dimensional render of the brain and tumour, this time combining each and every

[13] Havaci, Mohammad, et al. "Brain Tumor Segmentation with Deep Neural Networks." *Medical Image Analysis*, 23 May 2016, pp. 1–17.

individual incision to formulate the approximate pathway the surgeon must take to effectively remove the tumour. The beauty of this system is that it continually improves with each and every surgery. With this example in mind, legitimate improvements to the gamma knife radiosurgery can now be offered.

5. Making the Worlds Meet

Gamma knife radiosurgery can be simplified through the use of an augmented reality system that has been improved using a neural network, while the surgeon gains insight and guidance from a Deep Neural Network (DNN). This solution can be broken down into two segments; the visualization of the brain, and the actual procedure. Not only that, the software used for the gamma knife radiosurgery can be automated using the neural networks, thus providing an even better form of surgery.

5.1 Superimposing the Brain

One of the first tasks to be done is the superimposition of the brain. As mentioned earlier, an augmented reality system would superimpose a virtual image over the anatomical body of the patient. For this subtask, the first thing to do is create the image to overlay. To do this, we can use a DNN similar to the one used for the brain tumour segmentation program to identify the MRI/CT scan and create the necessary segmentations for the operation. Through the merging of various two-dimensional images of the MRI, the DNN can construct a three-dimensional anatomical scan of the brain for the surgeon.[11] The surgeon can then manipulate this data using an augmented reality system and analyze the proposed area for the radiosurgery. After making the necessary adjustments, the virtual brain imagery would be laid over the actual brain. One method is by manually aligning the virtual and real images based on visible landmarks. This would involve using the shape and size of the brain to properly align the virtual image with the brain. However, this method is very inaccurate and could potentially cause misalignments.[12] This is where the neural network comes in with another technique of association whereby it associates the virtual image with the real world image through a visual analysis of the brain. By scanning the brain, the computer now has a

real image to compare with the virtual image. This image is created through the use of an optical recognition system attached to the machine. Thus, the visualization of the brain is now complete, and the surgeon can begin the operation on the patient.

5.2 Adapting the Technology to fit the Current Equipment

The next and final step for this solution involves enacting the procedure onto the patient using the technology given to the surgeon. This technology can be improved so that it can most efficiently use the data obtained from the visualization of the brain. One thing that can be improved is the visualization method that the surgeon uses. Originally, the surgeon would view the anatomy and virtual model on a small monitor to the side of the patient. This reduces the precision of the procedure as the surgeons attention would be divided between the screen and the patient.[12] Instead, the surgeon could include this virtual image overlay on the gamma knife machine itself. The gamma knife program can overlay the target area over the brain image. This would use a neural-network based visualization system that would constantly feed visual information to the three-dimensional rendering machine of the augmented reality system. By using neural networks to store all data regarding previous surgeries, a new system can be created. This new system involving solely computers greatly reduces the margin for error. This data would allow for more accurate coordination of the various beams of gamma rays which would follow the precise border and margins created by the computer.

5.3 Analysis of Application

Through the combination of the above-mentioned surgical equipment with neural-network based augmented reality visualization system, a virtual image of the brain can be applied to the anatomical model of the patient. This would simplify the task of identifying the location of the gamma ray triangulation, while increasing the precision of the operation. This system would also better identify the gamma knife radiotherapy itself as it would highlight the particular parts of the brain which would need to be neutralized for the operation. Finally, this system would improve over time as it utilises two neural networks—a

regular artificial network, and a deep neural network—both of which keeps a storage of previous data and incorporates it into a database for future use. However, there arises some issues with the use of this application. One problem is that there exists larger room for error in the initial trials of this system. Hence, before the automated system of the gamma knife machine could be used, the surgeons must first collect data. This would mean surgeons would complete operations using the new and improved machine, and after a certain number of operations, can test out the reliability of the automated procedure. Finally, this system may cause humans to become less accurate in their procedures as they believe that the system will save them every time. This is why proper testing and data collection must first be conducted before this system can legitimately be used in lieu of other gamma knife machines.

6. Conclusion

The aim of this essay was to answer the following question : how can we use a combination of augmented reality with neural networks to facilitate easier and more accessible brain operations for all surgeons? This essay explored the implementation of augmented reality, the implementations of neural networks, and the procedure of gamma knife radiotherapy. After carefully procuring information regarding this three concepts, a potential method for which brain surgery can become easier and more accessible for surgeons was created. Through the use of a Deep Neural Network (DNN)-based visualization system, alongside technologically improved surgical equipment and an augmented reality system, a improved method for a gamma knife machine was created. Alongside that is a new concept of approach to this surgery that is purely automated. However, there exists issues with this method, such as accuracies at the initial point of operation for the program, and with the surgical visualization of the brain. With these in mind, further research must be done within neural networks to see if an improved algorithm can be created with a higher success rate at the onset of the program. Not only that, demonstration models would need to be created and distributed amongst surgeons to gain feedback on whether the visualization model effectively merges with the anatomical model of the patient. Overall, this research

opens the path to other implements of current technology, and introduces new methodologies to conduct and simplify previous operations for the betterment of society.

Works Cited

"A Basic Introduction to Neural Networks." *History of Cajun Country*, pages.cs.wisc.edu/~bolo/shipyard/neural/local.html.

Abdi, Hervé. "A Neural Network Primer." *Journal of Biological System*, vol. 2, Mar. 1994, pp. 247–283.

Azuma, Ronald, et al. "Recent Advances in Augmented Reality." *IEEE*, Nov. 2001.

Basheer, I A, and M Hajmeer. "Artificial Neural Networks: Fundamentals, Computing, Design, and Application." *Journal of Microbiological Methods*, vol. 43, 2000, pp. 3–31.

Britannica, The Editors of Encyclopaedia. "Brain." Encyclopædia Britannica, Encyclopædia Britannica, Inc., 9 Oct. 2018, www.britannica.com/science/brain.

Chang, Jin Hyuck et al. "Complications after gamma knife radiosurgery for benign meningiomas." Journal of neurology, neurosurgery, and psychiatry 74 2 (2003): 226-30 .

Fida, Benish et al. Augmented Reality in Open Surgery. Italian Society of Surgery. May, 30 2018.

"Gamma Knife Surgery, Advantages and Disadvantages of Gamma Knife." The Gamma Knife, 25 Apr. 2017, www.thegammaknife.com/advantages-disadvantages-gamma-knife/.

"Gamma Knife Radiosurgery - The Most Effective Treatments at Columbia Neurosurgery." Columbia Neurosurgery, www.columbianeurosurgery.org/treatments/gamma-knife-radiosurgery/.

Havaci, Mohammad, et al. "Brain Tumor Segmentation with Deep Neural Networks." *Medical Image Analysis*, 23 May 2016, pp. 1–17.

"IKEA Place Augmented Reality App." *IKEA Highlights 2017*, 2017, highlights.ikea.com/2017/ikea-place/.

Maung, Pye P. "Augmented Reality Using a Neural Network." *Department of Mathematics and Computer Science*, *Ripon College*, 9 Mar. 2012.

Pimental, Ken and Texeira, Kevin. Virtual Reality : Through the new looking glass. McGraw Hill. May 30, 1994.

Shepard, David M. et al. "Inverse treatment planning for Gamma Knife radiosurgery." Medical physics 27 12 (2000): 2748-56 .

Westwood, James D et al. Medicine Meets Virtual Reality 2000. IOS Press, 2000.

Wexelblat, Alan. Virtual Reality: Applications and Explorations. Academic Press, 1995.