Operating Room Ergonomics, Training and Assessment Algorithm using Virtual Reality and Machine Learning

by

Hind Hazza Alsharif

A thesis submitted for the requirements of the degree of Doctor of Philosophy in Computer Science

Faculty of Computing and Information Technology
King Abdulaziz University
Jeddah, Saudi Arabia
Rabi I 1443 H - November 2021 G

Operating Room Ergonomics, Training and Assessment Algorithm using Virtual Reality and Machine Learning

by

Hind Hazza Alsharif

A thesis submitted for the requirements of the degree of Doctor of Philosophy in Computer Science

Advisor

Prof. Wadee Alhalabi

Co-Advisor

Dr. Abdulrahman Sabbagh

Faculty of Computing and Information Technology
King Abdulaziz University
Jeddah, Saudi Arabia
Rabi I 1443 H - November 2021 G

بسم الله الرحمن الرحيم

Operating Room Ergonomics, Training and Assessment Algorithm using Virtual Reality and Machine Learning

by

Hind Hazza Alsharif

A thesis submitted for the requirements of the degree of Doctor of Philosophy in Computer Science

Name	Rank	Field	Signature
Advisor			
Prof. Wadee Alhalabi	Professor	Computer Science	
Co-Advisor			
Dr. Abdulrahman Sabbagh	Associate Professor	Neurosurgery	
Internal Examiner			
Dr. Aiiad Albeshri	Associate Professor	Computer Science	
External Examiner			
Prof. Miltiadis D. Lytras	Professor	Information Management Systems	

Faculty of Computing and Information Technology
King Abdulaziz University
Jeddah, Saudi Arabia
Rabi I 1443 H - November 2021 G

Copyright

Dedication

I hereby dedicate this work to all of my family members. It would not have been possible to write this dissertation without the continuous support, encouragement and love from them throughout this endeavor. To my dearest father Hazza, my mother Najwa, my sister and my brothers for always being supportive of my educational development and evolution.

To my beloved family, who was with me and support me through thick and thin. To my dear and kind husband, Tariq, for his unwavering patience and support in facilitating my academic aspiration and strive throughout our lives together and my four wonderful children, whose warmth and hugs during the time of tiredness and mental burnout will never be forgotten.

Acknowledgments

I thank God for all the opportunities, trials and strength that have been showered on me to finish writing this dissertation. I experienced so much during this process, not only from the academic aspect, but also from the aspect of personality development.

Firstly, I would like to express my sincere gratitude to my advisor, Prof. Wadee Alhalabi, for his continuous support of my Ph.D. study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this dissertation. I would like to express my gratitude to my dissertation Co-advisor, Dr. Abdulrahman Sabbagh, for giving me the right guidance and providing me with the much needed motivation to strive onwards.

I also would like to thank everyone who participated in this work, including Prof. Richard Satava, Prof. Saleh Baesa, Dr. Khlaid Bajunaid, Dr. Abdulhameed Alkhateeb, and Dr. Mirza Pasovic, who unselfishly rendered their time with us with their insightful comments and encouragement.

Many thanks to King Abdulaziz University Hospital, King Faisal Specialist Hospital, King Fahad Hospital, AlNoor Specialist Hospital, and National Guard Hospital that offered the access to their buildings to conduct my study in order to come up with a real-based study result.

Abstract

In the medical field, there has been an accentuated acknowledgement of the importance of ergonomics and the analysis of data. Due to long term standing, difficult body postures, and the need to exert pressure on tissues, neurosurgeons are subjected to occupational risks when performing open surgical operations. This dissertation is divided into two parts. The first part provides a training approach for residents that enable them to acquire the ergonomic skills needed for spine surgeries. The need to show if that Virtual Reality simulators can improve the ergonomics skill in residents. A Virtual Reality training simulator has been designed and implemented, the simulator measures two ergonomic skills need to be maintained during any surgery: neck angle and table height. The experiments showed that the users are usually focused on their work and tend to pay less attention to their body position and movements. This result in a bad ergonomics setup which leads to back and neck pain. Thus, the users need to be trained to have good ergonomics positions. In the proposed system, this is measured using a specific metric that collects head positions, angles, hands movements as well as elbow height and other parameters. The designed model showed that incorporating simulations into resident training, simulated surgeries will strengthen the surgeon's skills and outcomes. The second part of this dissertation aims to build a machine learning model utilizing some machine learning algorithms including YOLO, HOG, SVM, CNN, and VGG16 in order to estimate surgeons poses during operations. This technique will give a report that precisely measuring the ergonomic skills about the surgeons and the team.

Key Word: *ergonomics, training, surgery, simulation, algorithm*

Contents

Copyright **i**

Dedication **ii**

Acknowledgments **iii**

Abstract **iv**

List of Tables **xi**

List of Figures **xiii**

List of Abbreviations **xvi**

Chapter 1 Introduction **1**

1.1 Background 1

1.2 Statement of the Problem 5

1.3 Research Questions . . . 7
1.4 Research Objectives . . . 7
1.5 Hypothesis . . . 8
1.6 Research Methodology . . . 9
1.7 Research Contribution . . . 10

Chapter 2 Literature Review **11**
2.1 Simulation Background . . . 11
2.2 Advantages and Disadvantages of VR . . . 13
2.3 VR for Neurosurgery . . . 16
2.4 Ergonomics Importance in Neurosurgery . . . 19
2.5 Machine Learning Algorithms for Object Detection . . . 29

Chapter 3 Methodology **35**
3.1 Study 1: Ergonomics Skills Assessment using VR Technology . . . 35
3.1.1 Need Based Assessment . . . 36
3.1.2 Building the Simulator . . . 38
3.1.3 The VR Simulation Scenario . . . 43
3.1.4 VR System Architecture . . . 50

3.2 Study 2: Evaluation of Operating Room Compliance based on Ergonomics Skills 51
3.2.1 Study Design 51
3.2.2 Scope of the Study: 54
3.2.3 Algorithm: 54
3.2.4 Method#1 HOG+SVM: 55
3.2.5 Method#2 YOLO+CNN 56
3.2.5.1 Slope and Classification based 58
3.2.5.2 Slope and Regression based 60
3.3 Method#3 VGG16 62

Chapter 4 Results **64**

4.1 Study 1: Ergonomics Skills Assessment using VR Technology . . . 64
4.1.1 Need Based Assessment 65
4.1.1.1 Quantitative Analysis of the Survey 65
4.1.1.2 Qualitative Analysis of the Survey 70
4.1.2 Using the Simulator 79
4.1.3 Data Analysis for Neck Angle 83
4.1.4 Data Analysis for Hand Movements and Rotations 87

4.1.4.1 Interns Rotation Movement 87

4.1.4.2 Interns Position Movement 90

4.1.4.3 Consultants Rotation Movement 93

4.1.4.4 Consultants Position Movement 96

4.1.4.5 Residents Rotation Movement 99

4.1.4.6 Residents Position Movement 102

4.1.4.7 Specialists Rotation Movement 105

4.1.4.8 Specialists Position Movement 108

4.1.4.9 Consultants vs Residents 111

4.1.4.10 Specialists vs Interns 113

4.2 Study 2: Evaluation of Operating Room Compliance based on Ergonomics Skills 115

4.2.1 Method # 1 HOG+SVM Utilization 115

4.2.2 Method # 2 YOLO+CNN Utilization 116

4.2.3 Method # 3 VGG16 Utilization 117

Chapter 5 Discussion **118**

5.1 Study 1: Ergonomics Skills Assessment using VR Technology . . . 118

5.2 Study 2: Evaluation of Operating Room Compliance based on Ergonomics Skills . . . 122

Chapter 6 Conclusion **123**

6.1 Conclusion . . . 123

6.2 Future Work . . . 124

Appendix A **132**

List of Tables

4.1 Respondents' characteristics. 67

4.2 Gaps in existing neurosurgical training in the preoperative phase (Approach). 70

4.3 Key limitations of current approaches in surgery, with an emphasis in technological support. 71

4.4 Responders' experience in the use of technological tools in surgery. . 74

4.5 Average of descriptive statistics for each type of user. 84

4.6 Mean of head angle obtained by each user. 85

4.7 *t*-Test results for the comparison between Consultants and Residents. 86

4.8 *t*-Test results for the comparison between Residents and Interns. . . 86

4.9 Statistical indicators for the rotation movement of interns. 88

4.10 Statistical indicators for the position movement of interns. 91

4.11 Statistical indicators for the rotation movement of consultants. . . . 94

4.12 Statistical indicators for the rotation movement of consultants. . . . 97

4.13 Statistical indicators for the rotation movement of residents. 100

4.14 Statistical indicators for the position movement of residents. 103

4.15 Statistical indicators for the rotation movement of specialists. 106

4.16 Statistical indicators for the position movement of specialists. 109

4.17 Results of the statistics tests. 112

4.18 Results of the statistics tests. 113

List of Figures

3.1 The surgeon on the left stands with his head at a slight angle of around 15°-20° with right posture. The surgeon on the right has an inappropriate posture with highly flexed neck. 38

3.2 The right operating table's height indicated with operating surface at elbow level. 39

3.3 Proposed prototype scenario-building roadmap. 39

3.4 Circle passing through 3 points. 41

3.5 Oculus Quest. 44

3.6 Designed surgical instrument, 1- scalpel, 2- suction, 3- monopolar/bipolar, 4- retractors. 45

3.7 Instruments design using Blender. 45

3.8 Skin design using Blender. 46

3.9 Skin cut interaction using Unity platform. 46

3.10 3D virtual environment. 47

3.11 Yaw, pitch, roll movements. 47

3.12 System Block Diagram. 48

3.13 The operator making the incision. 49

3.14 Use a monopolar/bipolar and suction. 49

3.15 Use retractors to expand the wound area. 50

3.16 VR Architecture system. 51

3.17 HOG+SVM block diagram. 56

3.18 YOLO+CNN block diagram. 57

3.19 Slope estimation for neck angle. 61

3.20 Slope estimation for elbow height. 62

3.21 VGG-16 block diagram. 62

4.1 Common rehearsal methods. 68

4.2 Patient positioning technique importance. 70

4.3 Elbow height calculation guidelines. 80

4.4 Adjusting table height buttons. 80

4.5 Scalpel position calculation. 81

4.6 Cutting skin complete. 81

4.7 Participants from a) King Fahad Hospital, b) King Abdulaziz University Hospital, c) King Faisal Specialist Hospital, d) National Guard Hospital, and e) Alnoor Specialist Hospital. 82

4.8 Neck angle of A. consultants; B. residents; C. specialists; D. interns. 83

4.9 Histogram of the right-hand rotation on the x-axis for the interns. . . 89

4.10 Histogram of the right-hand rotation on the y-axis for the interns. . . 89

4.11 Histogram of the right-hand rotation on the z-axis for the interns. . . 90

4.12 Histogram of the right-hand position on the x-axis for the interns. . . 92

4.13 Histogram of the right-hand position on the y-axis for the interns. . 92

4.14 Histogram of the right-hand rotation on the z-axis for the interns. . . 93

4.15 Histogram of the right-hand rotation on the x-axis for the consultants. 95

4.16 Histogram of the right-hand rotation on the y-axis for the consultants. 95

4.17 Histogram of the right-hand rotation on the z-axis for the consultants. 96

4.18 Histogram of the right-hand position on the x-axis for the consultants. 98

4.19 Histogram of the right-hand position on the y-axis for the consultants. 98

4.20 Histogram of the right-hand position on the z-axis for the consultants. 99

4.21 Histogram of the right-hand rotation on the x-axis for the residents. . 101

4.22 Histogram of the right-hand rotation on the y-axis for the residents. . 101

4.23 Histogram of the right-hand rotation on the z-axis for the residents. . 102

4.24 Histogram of the right-hand position on the *x*-axis for the residents. 104

4.25 Histogram of the right-hand position on the *y*-axis for the residents. 104

4.26 Histogram of the right-hand position on the *z*-axis for the residents. . 105

4.27 Histogram of the right-hand rotation on the *x*-axis for the specialists. 107

4.28 Histogram of the right-hand rotation on the *y*-axis for the specialists. 107

4.29 Histogram of the right-hand rotation on the *z*-axis for the specialists. 108

4.30 Histogram of the right-hand position on the *x*-axis for the specialists. 110

4.31 Histogram of the right-hand position on the *y*-axis for the specialists. 110

4.32 Histogram of the right-hand position on the *z*-axis for the specialists. 111

4.33 The Friedman two-way analysis of variance by rank for the rotation movement on the *z*-axis. 112

4.34 Realism of the simulated spine surgery (1-completely unrealistic, 5-completely realistic). 114

4.35 Example of negative body posture. 116

4.36 Example of YOLO+CNN method output. 117

List of Abbreviations

AWG	Alternative Word Generator
CNN	Convolutional Neural Network
FC	Fully Connected
FLS	Fundamentals of Laparoscopic Surgery
HOG	Histogram of Oriented Gradients
MIS	Minimally Invasive Surgery
ML	Machine Learning
MLP	Multi-Layer Perceptron
MSD	Musculoskeletal Disorder
MVOR	Multi-View RGB-D Operating Room
NP	Needle Passage
OR	Operating Room

PT	Peg Transfer
SVM	Support Victor Machine
VR	Virtual Reality
WMSD	Work Musculoskeletal Disorder
YOLO	You Only Look Once

Chapter 1

Introduction

This chapter presents a brief background of simulation and its role in medical training as an educational tool. It also defines ergonomics and its implications in neurosurgery field. Next, this chapter delineates the statement of the problem followed by the research questions and objectives. In addition, the research contribution is stated and the conducted methodology is described.

1.1 Background

Surgery is a specialty that requires knowledge and responsibility for the patients' preoperative, operative, and postoperative management within a broad spectrum of diseases, including those which may require non-operative, elective, or emergency surgical treatment. The details and depth of this knowledge may vary by disease category. However, surgeons should be competent in the diagnosis level as well as in treatment and management [1].

Because of the increasing demands on trainees and duty hour restriction, the training opportunities are becoming slimmer. Therefore, according to Lui et al. [2], newer and more contemporary training methods such as Virtual Reality (VR), computer-based simulations technologies are needed. However, overall as well as specialty specific needs-based assessments are required to lead further work that will be directed towards the development of surgical simulation technologies.

Neurosurgery is one of the most demanding medical professions that engages a high level of expertise. It is a very challenging surgical specialty where techniques and technologies are constantly emerging. Some procedural treatments for nervous system diseases include surgery, which is mostly performed by a neurosurgeon (also known as a brain surgeon). There are wide ranges of different types of neurosurgery procedures ranging from minor and simple to quite difficult and complicated. Common types of neuro-surgical procedures include Spinal Fusion, Epilepsy Surgery, Burr Hole, Craniotomy, Microdiscectomy, Ventriculostomy, and so on [3].

Medical education is the key step in the acquisition of clinical skills for the overall improvement of patient care. As the volume of medical knowledge steadily increases, the complexity of treatment options increase. Therefore, it is essential that doctors and other care professionals acquire the skills to keep up- to -date in their field. Moreover, to be able to explain and justify their counseling to patients, trainees need to critically analyze new developments and to practice based on the best evidences available.

Simulation training in medical education referred to Rehder et al. is defined as *'a* *technique to replace or amplify real patient experiences with guided experiences, artificially contrived, and that evokes or replicates substantial aspects of the real world in a fully interactive manner'* [4].

As the field of neurosurgery continues to evolve, based on Aggarwal et al. study, it has become obvious that the operating room is not an ideal place for learning and acquiring initial surgical skills. If failure occurs, the sequence of actions in clinical training can't be often repeated. Simulation offers surgeons and trainees the opportunity to rehearse the procedure in advance and practice skills before actually touching the patient. Neurosurgical simulation presents realistic opportunities to enhance the safety and effectiveness of both classical and complex operative procedures [5].

According to Limbrick et al., currently, about 70 % of medical schools have already incorporated some simulation types in their curricula, especially in operational based specialties, such as general surgery, urology, and neurosurgery [6]. A recent survey of neurosurgery programs by Ganju et al. concluded that simulation is considered as an important tool to complement classical operative training [7]. While Durkin et al. stated that newer and effective methods gained interest and allowed the trainees to perform difficult tasks [8]. A study by Cohen et al. mentioned that neurosurgical trainees encounter great challenges in learning to plan and perform increasingly complex and critical procedures [9]. Referring to a study by Coelho et al., the authors proffered that the educator's task becomes more difficult and challenging as the number and complexity of neurosurgical operations continue to increase in parallel with technological developments such as minimally invasive spine surgery and instrumentation, interventional neuroangiography, image-guided navigation, and endoscopic surgery [10]. Moreover, Zanello et al. stated that residents are unable to meet with the demands to maximize training before being allowed to work on patients due to their work hour limitations. This two-fold need is the main reason for reconsidering resident training in all specialties [11].

Simulation-based skills training and assessment are increasingly incorporated into surgical education and certification processes as discussed in Atesok et al. study. Measurement techniques to identify the level of proficiency in the performance of surgical procedures will be the key element in the success of surgical education and training [12].

VR is defined by Alaraj et al.[13], as an application that can influence the procedural practice in neurosurgery training. Integration of this technologies in the medical education field is an important challenge for medical educators' due to its huge potential benefit on human health. Previous studies revealed that virtual reality simulators improved the operating room performance of surgical residents and reduced the patient risks.

Ergonomics, also called human factors, is the study of the behavior of individuals in relation to their working environment and the mechanical and electronic equipment operated by the worker. Berguer [14] in his study, outlined that the function of ergonomics specialists is to design or ameliorate the workplace, equipment, and procedures of workers, not only to achieve a safe, healthy, and efficient accomplishment of personal goals , but also those of the organization. Many surgeons will continue to experience pain and discomfort while performing operations at work, due to bad posture or as a result of the instruments they use, unless they get adequate training to improve their working practices or until departments in their organizations consider the ergonomics of surgery.

Ergonomic analysis is widely applied today–in industry, the military, and sports training–to help people achieve optimum performance with a low risk of error and injury as referred to by Berguer in another study [16]. In their study, Albayrak et al. stated that during surgery, ergonomic stress is of considerable importance. Due to the patient's position, surgeons tend to lean forward toward, or even over the surgical field to see and manipulate tissues; this results in increased muscle activity to balance the upper body. Moreover, awkward postures kept for long periods result in musculoskeletal fatigue and physical complaints [17]. In addition, due to the complexity involved and risk to the patient (when fine errors occur), some specialties require more practice than others.

1.2 Statement of the Problem

Residents are at an increased risk of work-related musculoskeletal pain and injuries since they are still inexperienced and thus have to perform physically challenging tasks such as surgical retraction. Junior surgeons are less acquainted with surgery and as a result may be subjected to a high level of emotional and psychological stress. Consequently, their main focus intraoperatively is the surgical technique, with less attention being given to their physical condition, surgical step, and ergonomic conditions. Therefore, Ronstrom et al. declared that it is imperative that ergonomic programs be implemented and surgical residents undergo ergonomic training, which will improve their understanding of the human-system interactions in the operating rooms [18].

Neurological surgery, in particular, is characterized by technically complex procedures that require long hours of training in order to minimize the risks to the patient. Therefore, improving training and education is important for both neurosurgeons and their patients. According to a study by Soueid et al. [15] 80% of neurosurgeons (8 out of 10) have the frequent occurrence of musculoskeletal pain that has been attributed to operating. For surgery residents, an injury may have direct consequences on their training. Therefore, the aim of this study is to understand the current perspectives and future vision and the need for simulation in neurosurgical training and practice.

An ergonomics task analysis and training can help identify the key components of surgical skill and ensure that students have appropriate and reliable training. Moreover, improvements and efficiency in training must be acquired outside the operating room. Therefore, training techniques can be applied through virtual reality; simulators have been proven to improve end-user skills in numerous fields and are now considered standard in training.

In this dissertation our focus is in the ergonomics problem due to the lack of technologies that concern similar deficiencies. We are also focusing on neurosurgical education and simulation.

1.3 Research Questions

The motivation behind our hypothesis is based on academic literature and subject matter experts. There is no similar product existing to measure the attributes we are measuring and evaluating. Finally, the research questions that can be asked are as follow: How we will solve the ergonomics deficiencies on the trainees? Does VR technology help in these kinds of problems? Can VR technology evaluate the ergonomic skills? Does the intended method give efficient results and solve the problem that we stated in our hypothesis?

1.4 Research Objectives

The objectives of our dissertation are as follow: (1) To achieve improvements of ergonomic skills for residents. (2) To Build simulators and computers that can replace patients in surgical preparation. (3) Design an algorithm to measure the compliance of ergonomics skills from body postures. (4) To enhance student learning in complex and critical procedures with minimum error and validate the ability of the exercises to teach the desired skill or technique. (5) To handle training and rehearsal gaps that have never been addressed by simulation technologies, such as OR ergonomics skills. (6) Learning ideal ergonomic practices that could improve physical health and well-being for surgeons as well as support career longevity.

1.5 Hypothesis

Our hypothesis states the following:

1. If we train residents using VR technology, we expect an increase in their performance. In other words, it would boost their performance.

2. VR simulator is as good as other existing methods in enhancing ergonomic skills.

   Where

   H_0 : *the null hypothesis*

   μ_0 : mean in the VR simulator

   μ_1 : mean of the existing methods in enhancing ergonomic skills

   So $\mu_0 = \mu_1$

3. Ergonomic skills for consultants, specialists, residents, and interns have the same level.

Where

H_0 : *the null hypothesis*

μ_0 : mean of ergonomic skills for consultants

μ_1 : mean of ergonomic skills for specialists

μ_2 : mean of ergonomic skills for residents

μ_3 : mean of ergonomic skills for interns

So $\mu_0 = \mu_1 = \mu_2 = \mu_3$

4. Using image processing can detect ergonomic skills with high accuracy.

1.6 Research Methodology

This Research is divided into two outcomes. First, a software product can be used to train the residents and enhance their ergonomics skills. Second, an objective assessment system for surgeons aiming to evaluate and measure their ergonomic skills in the operating room.

This Research aims to design and implement a low cost-effective and high-quality virtual reality simulator to evaluate neurosurgeon's ergonomics in term of neck angle and patient table height. Moreover, we aim to build a machine learning model utilizing some algorithms including YOLO, HOG, SVM, CNN, and VGG16 in order to estimate surgeons pose during an operation. This technique will give us the information about the surgeons and the team including nurses, assistants, residents and others. The algorithm will give a report at the end precisely measuring the ergonomic skills.

1.7 Research Contribution

The main contribution in this work is as follow:

1. Design and implementation of an algorithm that use VR to train residences on surgical ergonomic skills in the OR.

2. Design and implementation of an algorithm that use ML to evaluate surgical ergonomic skills in the OR.

Chapter 2

Literature Review

This chapter provides a definitive insight into simulation's background and its applications in medical training, this chapter also discusses the advantages and disadvantages of VR simulations. Moreover, existing neurosurgical VR simulators are explored, while the concept of ergonomics and its impact in neurosurgery are succinctly detailed. Furthermore, object detection machine learning algorithms that have been used in this research are explained. These algorithms include YOLO, SVM, HOG, CNN, and VGG16.

2.1 Simulation Background

Simulation involves the use of models to represent real-life experiences. It has gained wide acceptance in many areas, including aviation, military training (war games), and medicine (cadaveric dissection) [4]. In aviation industry, flight simulator was recorded as early as 1909. Simulation training in the military and commercial sector continues to grow, with various applications from aircraft to nuclear submarines [19]. Many of these fields have high-stake situations in which errors or failures may have catastrophic consequences. As such, there has been a great deal of benefits in encouraging practitioners and trainees to improve their skills, refine strategies, and avoid costly errors before working in the real world.

The idea of simulation was derived from primitive flight simulators in the United States. It took more than 20 years, from late 1930 until 1955, until the Federal Aviation Administration of the USA validated flight simulators and adopted them as a necessary prerequisite for annual flight certification [20].

The use of simulation in the field of surgical education was introduced many years ago. There is evidence that Egyptian surgeons priests may have simulated rhinoplasty on cadavers that were being prepared for mummification in 2000 BC [21]. Animal and cadaver simulation models were the first to have the highest fidelity simulations. One big drawback is that the animal or cadaver can only be used once for each organ for simulation. That is to say, there is an inability to repeat simulation or recreate it. Another disadvantage is the high cost, along with the medico-legal and ethical concerns arising from animal and cadaver use. Nevertheless, simulation of the cadaver model, particularly the human cadaver model of Thiel (preserved cadaver using a technique that preserves human tissue in a non-rigid form similar to that found in a living human), resembles in vivo conditions and as such is preferred to any other model of simulation [21].

While the use of cadavers and animal models in surgical education has long been used, the simulation of virtual reality (VR) was first used in surgical education in 1987 and was made popular in the early 1990s. Simulation in surgery became an area of great creativity and burgeoning study from that moment on [19]. Unlike previous high-fidelity models, video and web-based simulation include low cost, simulator portability and the ability to train a large number of trainees at the same time [21].

Mechanical simulators are the most commonly used, and are well known in surgical training for their application. The most popular form is the box trainer model which consists of a camera, light source, monitor, and laparoscopic tools. This method has variations, mostly with a view to reduce costs and complexity. The MISTELS (McGill Inanimate System for Training and Evaluation of Laparoscopic Skills) and the University of Kentucky's (UK) programmers are both sophisticated teaching models for box-trainer skills that have been developed and validated. In recent years the simulation based on mannequins has become very popular. These simulators are already appropriate in surgical training as an effective simulation activity, particularly in trauma or a difficult airway [21].

2.2 Advantages and Disadvantages of VR

VR is an evolving technology that can be used in many fields. It can be seen as a combination of human-computer interfaces, graphics, sensor technology, high-end computing and other modern technologies that all work together to allow a user to interact effectively with a computer-generated artificial environment [22].

In 1993, Satava et al. first proposed the application of VR simulation in surgical training to deliver measurable, consistent models that allow endless practice using standardized anatomy [22]. Many VR simulations are currently being developed and implemented, including full-patient models of anatomy, immersive 3D rendering of medical images, skill simulators, and simulations of many basic surgical procedures, such as leg surgery or laparoscopic surgery [22].

Training operational tasks via repeated, proctored sessions have been demonstrated to enhance identification and analysis of surgical error [23]. Previous research has shown that simulator training supports a wide variety of medical skills in terms of speed and accuracy of the residents' training [24, 25, 26] and that these skills contribute to better treatment and reduce patient pain and risks [27]. In addition, there are important evidences that support the use of VR simulators in surgical training. It has been found that VR simulation decreases operating time and increases the efficiency of surgical trainees. In addition, performance metrics provided by VR simulators have been shown to correlate strongly with the performance of the operating room [23].

Popular metrics created by VR simulators include time to complete a task, errors made while in surgery, and the economy of movement of the surgeons. These metrics have a framework that is analytical and quantitative for measuring skills. VR simulators thus provide a clear advantage over other simulators by allowing trainees to practice repeatedly and unsupervised while getting direct input from the simulator itself. In addition, the haptic metrics provided by VR simulators enable educators to evaluate and monitor the development of the skills of inexperienced surgeons. For example, as done by the Royal College of Physicians and Surgeons of Canada, better comparability between trainees provides a basis for evaluating and certifying trainees [28].

Modern VR simulators offer fully reusable simulations of high fidelity and are anatomically valid. In addition, surgical trainees can practice various simulations on a single unit since VR simulators are computer-based. The NeuroTouch VR neurosurgery simulator, for example, allows microdissection, tumor aspiration, debulking, and haemostasis simulation [23].

As their reliance on video monitoring makes them naturally suited to the VR platform, most VR simulators are designed to teach laparoscopic and endoscopic procedures. It is popular to use both low-fidelity simulators ('Task Trainers') that teach simple surgical procedures and high-fidelity models on complete operations. The MIST-VR system, for example, is a low-fidelity system designed to teach basic skills in laparoscopy, suturing, and knot-tying. The LapSim, Lap Tutor, and NeuroTouch are high fidelity VR systems. The Lap Tutor is a highly inclusive scheme, covering more than 65 cases in general surgery, gynecology, urology, and bariatric surgery [23].

VR-based simulators provide virtually unconstrained training experiences, raising their frequency and reducing the tools used because they are independent of the availability of patients or cadavers. Not only are cardiac patients costly and time-consuming to plan for a procedure, but they are also most often inaccessible, ethically problematic, and potentially dangerous, [28] therefore, making surgical cadaver training less appealing for the use as a practical and authentic simulated training environments. Simulation-based training, though, is costly, but so is conventional training [27].

Synthetic models are also not reusable, and thus, synthetic models with higher precision are very expensive compared to VR simulators. VR-based training may also be tailored to the skills and expertise of the surgical trainee by changing the level of difficulty or by providing incremental learning knowledge. VR-based simulators may be used to analyze factors affecting surgeon performance without placing patients at risk, such as operating room (OR) adverse conditions [27].

The drawbacks of VR simulations include high costs, lack of force-feedback, and some simulation models' minimal realism. However, simulators are becoming more cost-effective and better able to simulate human anatomy as VR technology progresses. Because of the flexibility of VR systems and the proof of their effectiveness in improving operational efficiency, it was suggested that these simulators be included formally in the surgical curricula [27].

2.3 VR for Neurosurgery

The use of simulation in training surgical residents is a domain of increasingly growing popularity and research. The increasing use of surgical simulation has been embraced by several factors, including required resident work-hour limits, increased demand for hospital quality, and a greater focus on patient-centered treatment with closer supervision by attending physicians. In addition, there are concerns that the conventional Halstedian surgical mentoring model may restrict the efficiency of acquiring surgical skills in an age where residents are required to master an enormous amount of knowledge. Simulation enables residents to learn skills in a risk-free environment, especially in the field of neurosurgery [23].

Neurosurgery is a challenging field that requires critical decision, professional experience, and careful concentration. A requirement for all neurosurgeons is the mastery of basic professional skills to provide secure patient care. The treatment of life-threatening neurological disorders becomes second nature by the end of residency training, but basic skills have to be sharpened like any technique. In general neurosurgery, simulators are useful for the training of junior residents and for the continuing education of subspecialized neurosurgeons who need to provide their populations with general call services on an irregular basis. Also, as the neurosurgery field continues to develop, it has become apparent that the operating room is not the best place to initially learn and improve surgical skills. If failure happens, the series of maneuvers in clinical practice will seldom be repeated [4].

Given these reasons, interest in neurosurgical simulation has recently surged. This is primarily due to the confluence of two synchronous factors: decreased exposure of trainees to surgical cases based on duty-hour residency constraints and technical developments in imagery, computing, virtual reality, (VR) and simulation 3D printing [4].

The use of VR in neurosurgery education has considerable potential to improve the training of surgeons. In the future, VR will almost certainly become a core component of resident education as explorations grow in computing, graphics, modeling, and haptic (tactile feedback) technology. Currently, however, VR simulation has been shown to be of value to the training of neurosurgeons [19].

Around the turn of this century, the earliest VR spine simulators were designed. Several VR simulators have since been developed commercially. ImmersiveTouch® is known as the simulator with potentially the most testing validation in the literature (Immersive Touch, Inc., Chicago, Illinois). Currently, this simulator models the following spinal procedures: percutaneous lumbar puncture, Jamshidi needle biopsy, positioning of the thoracic and lumbar pedicle screw, percutaneous spinal fixation, and vertebroplasty. According to the company website, several other procedures are under development, including anterior cervical discectomy, lateral mass fixation, etc. In the literature, a simulator called the Dextroscope® (Volume Interactions Pte, Ltd., Singapore) was also assessed. This framework focuses on preoperative preparation, enabling surgeons to imagine patient-specific anatomy by constructing a virtual surgical area in a 3D world [19]. However, this simulator is no longer being used.

Rather than assessing surgical procedures, simulation models can be used in different aspects. The NeuroTouch virtual reality simulator was used by Khalid et al. [29] to build and validate a set of methods for testing technical skills that can assess bimanual psychomotor performance skills. The study aimed to explore the impact of a simulated stressful virtual reality tumor resection scenario by utilizing NeuroTouch that allow the testing of acute stress on psychomotor performance in risk-free environments.

2.4 Ergonomics Importance in Neurosurgery

Ergonomics, also called human factors engineering, is the study of the behavior and activities of individuals concerning the work environment and the worker's mechanical and electronic equipment. The role of ergonomics specialists is to design or develop the workplace, equipment, and procedures of employees to ensure the comfortable, secure and efficient fulfillment of personal and organizational objectives. Studying human work, ergonomics has provided substantial insight into the mental and physical processes that workers need in many various environments. Such expertise has been effectively used in industrial and military settings to improve working conditions, minimize accident rates, and lower costs. Remarkably, only limited applications to the medical profession, particularly surgeons, have seen this scientific approach to work analysis [14]

Ergonomic analyses are commonly used today in technology, the military, and sports training to help people gain a maximum per-growth understanding of the value of ergonomics and ergonomic issues in relation to intensive care units, gastrointestinal endoscopy, back injuries in health care personnel, and job challenges in nurses and medical surgical staff. Anesthesiologists have discussed the significant factors in the display of knowledge and equipment design that influence their work, maybe more than any other medical specialty [16].

The risks of ergonomics in the OR can be divided into three groups: risks from physical ergonomics, risks of cognitive ergonomics, and risks from organizational ergonomics. Risks from physical ergonomics in the operating room are related to physical activity. And physical ergonomics deals with human anatomical, anthropometric, physiological, and biomechanical characteristics. Risks to cognitive ergonomics in the operating room are related to mental processes such as perception, thinking, and motor response and are concerned with cognitive ergonomics, as they influence the human experiences and other elements of a system. Lastly, risks from organizational ergonomics are concerned with the optimization of technical frameworks, including their organizational structures, strategies, and procedures [30].

Standing, uncomfortable body positions and the occasional need to exert significant pressures on tissues have almost always been needed to conduct open surgical procedures. It is well recognized in industrial ergonomics that both static and dynamic postural stress can lead to illness and discomfort [16].

Kant et al. studied the postures of doctors and nurses during surgery and found that, due to their frequent and sustained static head-bent and back-bent postures, surgeons and scrub nurses experience considerable stress on the musculoskeletal system [31]. Radermacher et al. have stated that more than 70 percent of intraoperative working postures are significantly unchanged during laparoscopic and orthopedic surgery [32]. Mirbod and others surveyed Musculoskeletal Disorders (MSD) among orthopedic and general surgeons and found a large prevalence of pain complaints among orthopedic surgeons in the shoulders (32%) and neck (39%). In the same study, with a prevalence of 18 percent and 21 percent, general surgeons reported similar symptoms compared to pharmacists at 15%t and 18% respectively [33].

Many surgeons, due to bad posture or as a result of the instruments they use, will continue to experience pain and discomfort while performing operations at work, unless they get adequate training to improve their working practices or until departments in their organizations consider the ergonomics of surgery. Neurological surgery, in particular, is characterized by technically complex procedures that require long hours of training to minimize the risk to the patient. Therefore, improving training and education is important for both neurosurgeons and their patients. According to a study by Soueid et al. [15], 80% of neurosurgeons (8 out of 10) have a prevalence of musculoskeletal pain that has been attributed to operating. For surgery residents, an injury may have direct consequences on their training. Therefore, the aim of this study is to understand the current perspectives and future vision and the need for simulation in neurosurgical training and practice.

During long periods of suturing, sitting is more restful and also offers a more secure posture during microsurgery for controlling equipment. In fact, a sitting posture has long been known as a favored position for light manipulative work, and proposals were made to enable surgeons to take a sitting position during at least part of an operation. However, sitting during major torso or limb surgery remains rare in the United States [16].

The risk of musculoskeletal problems in spine surgeons is even higher; member surveys released by both the North American Spine Society and the Scoliosis Research Society showed an unprecedented presence of neck and back pain in spine surgeons, resulting in medical care, missing work days, and early retirement. Rates of surgical care for these complaints varied from 4.6-7.1% [34]. During both open and laparoscopic procedures, surgeons are at risk of developing musculoskeletal strain [35].

Several studies have indicated that between 60-90% of surgeons experienced pain and discomfort from poor ergonomic positioning in the operating room. The fact that up to 40 percent of proceduralists indicates that pain and discomfort will impair their ability to perform or assist with surgical procedures in the future is also of paramount concern. In reality, two-thirds of the surgeons have little or no knowledge of the ergonomic factors that led to their symptoms [36]. Approximately 25% of those surgeons who reported discomfort took time-off from work with still more surgeons opting to decrease their operating caseload. An average of 7.3 days is lost when an injury results in the absence from work [50]. In addition, some surgeons recommend early retirement and fear that pain will shorten their careers [18].

For surgery, residents may have a direct effect on their preparation and could lead to direct consequences on their training. In a study of work-related injuries suffered during obstetrics and gynecology training, Yoong et al. found that out of 97 residents, 28 (29%) had sustained in-work injuries. Eight respondents needed time off from residency, and one had to extend the training by 3 months [37]. In addition, the risk factors for injury are both an absence of surgical experience and inadequate ergonomic preparation. Surgery residents may also have specific occupational injury risk factors since they have less experience and are often expected to perform physically challenging tasks. Moreover, with less attention paid to their physical status, surgical configuration, or other ergonomic factors, their primary intraoperative emphasis would be on the surgical procedure. Therefore, ergonomic education during residency can opportunely be mitigated [18].

Overall, open surgery is considered to be more ergonomic than laparoscopic surgery because it facilitates direct visualization, greater range of motion, fewer constrained postures and ease of movement [38, 39]. For this reason, the ergonomics of open surgery have not been well researched as minimally invasive surgery (MIS). Special ergonomic problems, however, occur during open procedures. In fact, up to 54% of the time surgeons spent with their head bent forward and 27% of the time spent with their back twisted and bent laterally. The asymmetric loading of the spine that occurs in these postures leads to an increased risk of vertebral disc herniation. Furthermore, the common view that open surgery is more ergonomic than laparoscopic is now questioned, since upper extremity electromyography studies show increased activity in open cases compared to laparoscopic 0-n n-' cases [18].

A lack of knowledge of ergonomic standards tends to be one of the most significant risk factors for surgical injury. Up to 90% of surgeons do not have previous ergonomics training [40, 41], and the lack of ergonomic preparation in surgeons has been directly related to occupational injury. Surgeons are at a higher risk of injury without an understanding of ergonomic variables to avoid strain. By introducing and educating residents in ergonomic concepts that can be easily adapted to the work of the surgeon inside and outside the operating room, surgeons as educators can mitigate this risk. Learning optimal ergonomic practices will improve surgeons' physical health and well-being and foster career continuation [18].

The importance of posture is often overlooked. Surgeons are often found in uncomfortable positions which cause musculoskeletal strain while operating. Although when working with proper body posture, if static and held with tension, it may lead to muscle fatigue [42, 43]. Furthermore, poor body positioning can negatively impact technical performance [44]. In the operating room lack of attention to ergonomic standards raises the risk of musculoskeletal discomfort. This may be particularly true for residents who pay little attention to ergonomic factors, including their posture, when concentrating on the operative procedure. Surgical training may be extended if an occupational accident happens, directly impacting the future of a resident as well as the residency program. Evidence indicates that the performance of trainees and surgeons increases when there is more attention to enhance the posture and control position and table height [18].

For cases that involve wide movements or substantial force, working while standing is optimal. The ideal standing pose is slightly tucked with the head directly over the shoulders and with the chin so that the neck is flexed at 15-25 degrees [45, 46, 47]. Improper table height can contribute to pain in the wrist, hand, shoulder, neck, and back. Proper adjustment of the height of the operating table decreases the risk of experiencing musculoskeletal discomfort by 83% [18].

For manual work, it is recommended to have a working height about 5 cm below the elbow with a reasonable range of 10 cm below (for heavy work) to 5 cm above the elbow height (for precision work). Most surgeons change the table during open operations, so the patient is at elbow height [18]. With one operating room table, however, it is rarely possible to change it to fit all the surgical team members. The teams ranged in height from barely five feet (5') to six feet five inches (6'5") during the observation of surgical processes. In most cases, the table height for the lead surgeon should be changed. It also became apparent that if the procedure was done from a seated position, it was much easier to accommodate more of the team [36].

During and after spine surgery, many spine surgeons reported neck and back pain. The spine angle of the surgeon was ergonomically examined in a study by Park et al. [48] during the surgery and the kinematics of the spine of the surgeon were correlated with musculoskeletal exhaustion and pain. In their experiment, 18 spine surgeons were included who each used a spine surgery simulator. Three different methods were used to visualize the surgical field (naked eye, loupe, microscope) and three different operating table heights were studied. A 16-camera optoelectronic motion analysis system was used, and 16 markers were placed from the head to the lower back. Measurements were compared between different operating table heights and visualization methods and also with natural standing posture. Results showed that spine angles were different depending on visualization method operating table heights. Their study suggests the use of a micro-scope and a table height above the umbilicus as an appropriate setting to reduce surgeon musculoskeletal discomfort.

Experts, in a study by Christian et al. [49] presented a systematic evaluation of an implementation of a participatory ergonomic training program in a medical-technical production company. One hundred and sixteen (116) employees in the company were included in this comprehensive ergonomic training. The purpose of their study was the evaluation of the implementation of an ergonomic training initiative in a single-case study which included basic and follow-up workshops attendance. For the organization, one of the study's practical goals was to optimize the learning transfer of the newly established ergonomic training program. Their study showed a successful ergonomic improvement.

Norashikin et al. [50] study explored whether MSD can be reduced by the provision of ergonomics education among computer users. Three units were randomly assigned for intervention and got training, while three units were given a booklet in a cluster randomized controlled trial. The intervention's impact on work-station behaviors, musculoskeletal disorders, sick leave, and psychological well-being were evaluated. As a result, work-station behaviors improved significantly, and the variations in keyboard, mouse, chair, and desk use remained significant at the follow-up time point.

Park et al. [51] noted that fatigue reduction was ergonomically demonstrated as feasible when laparoscopic surgeons adjust posture. Therefore, from the viewpoint of ergonomic and human factors, all measures must be extended to improve the surgeon, computer, and patient interface.

In their recent research study [52] the effects of different surgical simulation training programs on motor-skill acquisition were examined by Ritter et al. In their study, they conducted laparoscopic training activities to learning sessions and assessed the efficiency and earned learning curve, demonstrating that more training resulted in less time for tasks completion. Rodrigues et al. [53] recently conducted an Ergonomics Analysis for Subjective and Objective Fatigue in Surgeons Performing Laparoscopic and Robotic Surgical Skills Practice. Two standardized surgical tasks (peg transfer (PT) and needle passage (NP)) were completed twice in each surgical skill's practical situations in their experiment and study: (1) laparoscopic training-box environment (Fundamentals of Laparoscopic Surgery (FLS)) and (2) Mimic dV-trainer (MIMIC). One of their primary findings was that ergonomics settings and associated drawbacks have an overall impact on operational efficiency. In the context of this study, surgeon training is also a critical success factor for robotic surgery.

In their research work, Wu et al. [54] used sensor technology to develop performance indicators for robotic surgery training sessions. The major findings linked significant differences in performance between sessions to a variety of behavioral and cognitive markers. This means that effective surgery training must also incorporate these aspects as additional enhancing components.

The principle of ergonomics instruction validation was examined in Mertens et al. research [55] with a focus on robot-assisted surgical simulator training. The researchers' methodological trial and the use of the DaVinci skills simulator revealed that ergonomics teaching leads to improved scores and performance. This is a clear indicator that the ergonomics design of VR and simulation platforms must also be considered.

More detailed studies [56] provide a greater emphasis on crisis management simulations, which promote unique training experiences in areas such as dual neurosurgery and anesthesia. The design and requirements of a training simulation environment are challenged by the support of a team for resolving intraoperative crisis.

An important result was the requirement for continual simulation integration into ordinary training methods. Such a critical requirement necessitates the addition of Surgical Ergonomics to training. Ronstrom et al. addressed the importance of ergonomics professionals as educators in their study. The study's main conclusion is that residents should be taught how to employ ergonomics in the operating room [18]. The complexity of surgical activities demands the development and deployment of multi-procedural Virtual Reality simulators [57, 58], with a focus on interactivity and integration.

Yadav et al. [59] investigated the theory of Micro-neurosurgical Skills Training and concluded, among other things, that understanding ergonomics can greatly improve surgical skills, whereas Azarnoush et al. [60] investigated the impact of “force” in VR for brain tumor removal. By deploying NeuroVR (previously NeuroTouch), they could increase patient safety by combining force application and use in neurosurgeons with ergonomics data.

It is practically possible to study the concepts of ergonomics rather than train someone in ergonomics, which involves physical exercise. In the construction of equipment, systems or instruments, most ergonomic methods are employed. Using simulator to teach the ergonomics concepts with negative and positive examples of ergonomics or interactive application can be applied on a computer or in VR technology. The application will be focused on the selected competencies in ergonomics that can be assessed during practice. These measurements can be read through the simulator device for example, the user’s neck angle or the hand movements. The VR device trains the surgeon for specific period of time and gives a report on these measurements.

2.5 Machine Learning Algorithms for Object Detection

The detection of objects is an important stage in high-level computer vision. In order to fully understand images and analyze videos, accurate object detection is needed. In photographs and videos, faces and human bodies are among the most significant items. Two main steps for accurate human identification in a static image are feature extraction and classifier design [61].

The aim of object detection research is to figure out where objects are in a given image (object localization) and which group each object belongs to (classification of objects). Standard object detection models' pipelines can thus be divided into three phases: informative area selection, feature extraction, and classification [61].

Convolutional Neural Networks (ConvNet/CNN) are the most generally used Deep learning technique in the field of Computer Vision; they are commonly used to address image and vision-related issues, such as picture categorization, object detection, and pattern recognition. CNNs can be viewed as several images being filtered in parallel at the same time. It is a technique that can take an input image and learn its many elements (features) by assigning priority to them using learnable weights (particular pixel values of a matrix/vector) and biases to distinguish them in later stages [62].

CNNs do this learning by preserving an image's spatial and temporal relationships without losing key information by applying relevant filters, and once a match is made, that particular filter weight is learned and reused in the following stages as needed. As it goes deeper into the network, CNNs tend to reduce in size in relation to the network's depth with preserving image features [62].

The components of a Convolutional Neural Network structure are Convolutional layers, Pooling Layers, Activation Function, Loss Function, and Fully Connected Layer. The Convolutional layers are responsible for applying a kernel, mask, or template to the input image to generate a convolved output. To minimize the spatial dimensions of the convolved feature vector, pooling layers are inserted after each convolutional layer in the base architecture for compression purposes. This layer is intended to lower the computational resources required for data processing by reducing the dimensionality of the data [62].

The Fully Connected (FC) layer primarily learns non-linear combinations of high-level feature representations of the outputs from all previous convolutions and translates them into a suitable form to be given as input to a Neural Network for classification or prediction. After convolutional layers and fully connected layers, activation functions are employed to activate a neuron to signify its priority over other neurons in the same layer. Loss/Cost functions influence the model's performance intensity, and the cross-entropy loss is used in the softmax classifier, which is commonly used in neural networks [62].

YOLO (you only look once), is a state of the real-time object detection algorithm. It's a convolutional neural network (CNN) that detects objects in real time. The algorithm scans the entire image into a single neural network, splits it into regions, and predicts bounding boxes and probabilities for each. With YOLO, a single CNN predicts several bounding boxes and class probabilities for certain boxes at the same time. YOLO optimizes the detection quality immediately after training on complete images. The model's key advantages are that it is fast, that it sees the entire image during training and testing, and that it detects objects with a single convolutional network [63].

The Histogram of Oriented Gradients (HOG) is a feature descriptor used in computer vision and image processing for object detection. The technique counts the number of times a gradient orientation occurs in a specific area of an image. It's a condensed image representation that only shows the most interesting aspects of the image. The HOG investigates an object's structure or form. It also can provide edge direction by extracting the gradient and orientation of the edges. The orientations are determined in sections that are 'localized'. The entire image is divided into smaller regions, with each region's gradients and orientation determined separately [61].

The Support Vector Machine (SVM) is a classification and regression prediction method that employs machine learning theory to optimize accuracy while avoiding overfitting the data. Pixel maps are used as data in SVM, which makes it famous. Its performance is comparable to that of advanced neural networks. It's used in a variety of applications, including handwriting analysis, face analysis, and so on, with a focus on pattern classification and regression [64].

VGG16 is a convolutional neural network model proposed by K. Simonyan and A. Zisserman from the University of Oxford. Their contribution was a thorough evaluation of networks of increasing depth using an architecture with very small (3×3) convolution filters, which shows that a significant improvement on the prior-art configurations can be achieved by pushing the depth to 16–19 weight layers. VGG16 is a large-scale image classification network with very deep convolutional networks (up to 19 weight layers). On the ImageNet challenge dataset, it was demonstrated that the depth of representation is beneficial to classification accuracy and that state-of-the-art efficiency can be achieved using a conventional ConvNet architecture with significantly improved depth. VGG16 models generalize well to a wide variety of tasks and datasets, approaching or surpassing more complex recognition pipelines based on shallower image representations [65].

The problem of identifying the location of key points on the body, such as major body parts and joints, is known as human pose estimation. This problem has several applications, including behavior classification and body movement prediction. Due to small joints, occlusions, and the need to capture context, identifying body key points has proven to be a difficult issue [66].

Changbo et al. [67] described a method for extracting a human movement silhouette and matching it to a parametric model for human posture recognition using a genetic algorithm. Their work is divided into two parts. In the first step, a human silhouette is extracted from complex background under a fixed camera through a statistical method. In the second step, a genetic algorithm is employed to fit the human body's outline to a parametric shape space model. Experiments on real video sequences reveal that their technique can accurately extract human models.

An ergonomic posture recognition method based on 3D view-invariant features from a single 2D camera was proposed in Hong et al. [68] paper. View-in-variant relative 3D joint position (R3DJP) and joint angle are extracted as classification features based on the detected 2D skeletons using a multi-stage convolutional neural network (CNN) architecture. Three posture classifiers for the arms, back, and legs have been trained to classify them all at the same time in a single video frame. The accuracy of three body components in recognizing posture was 98.6%, 99.5%, and 99.8%, respectively. The relevant accuracies for generalization ability were 94.9%, 93.9%, and 94.6%, respectively. The method outperformed earlier vision-based methods in construction in terms of classification accuracy and generalization ability.

In their paper [69] Zequn et al. introduced a novel human posture identification approach based on the Microsoft Kinect sensor that can detect user-defined postures automatically. Nine features representing specific body parts such as the forearm, thigh, and so on were generated using skeleton information derived from a depth image of the user's posture. These characteristics are loaded into SVM, which generates posture-learning models, which are then used to recognize pre-defined postures. Performance evaluation using 10-fold cross-validation revealed that the method was capable of achieving a final overall accuracy of 99.14% in the test.

In Shumei and Victor's paper [70], an adaptive hybrid classifier (hAHC) was presented and assessed, which combines a posture-based adaptive signal segmentation algorithm with a multi-layer perceptron (MLP) classifier, as well as a plurality voting strategy. A real-time posture recognition framework based on simulated crowd security scenarios was used to test the hAHC model. It was compared to a single MLP classifier (sMLP) and a static hybrid classifier (hSHC) using the real-time information acquired from unfamiliar subjects from different approaches (classification precision, recall, and F1-score). The hAHC model enhanced classification accuracy and robustness slightly more than the hSHC model, and much more than the sMLP model, according to experimental results (hAHC 82% ; hSHC 79% ; sMLP 71%).

Chapter 3

Methodology

In this chapter, we will explain two major studies in detail. The first study intends to utilize VR technology to teach neurosurgical residents the ergonomics skills needed to be learned while operating on an open spine surgery. The second study aims to design a machine learning algorithm to detect ergonomic attributes while working in the operation room.

3.1 Study 1: Ergonomics Skills Assessment using VR Technology

This part explains the utilization of VR technology to teach neurosurgical residents the ergonomics skills needed to be learned while operating on an open spine surgery. it defines the creation stages of the designed VR simulator including a need-based assessment, simulator scenario and VR system architecture.

3.1.1 Need Based Assessment

To design the first study, we need to determine the prerequisites of neurosurgical training in order to strategize the future plans for simulation and rehearsal. Several meetings have been conducted in the simulation center, King Abdulaziz University Hospital (KAU-H), with subject matter experts, including Prof. Richard Satava (Professor Emeritus of Surgery, University of Washington), Dr. Abdulrahman Sabbagh, Prof. Saleh Baesa and Dr. Khalid Bajunaid (Department of Neurosurgery, KAU), Dr. Abdulhameed Alkhateeb, and Dr. Mirza Pasovic (department of biomedical Engineering, KAU). These meetings lasted for five to six months in order to identify the research problem. Firstly, we had to select a specific problem to be addressed in our research. Secondly, we wanted to determine the inputs, the expected outcomes of the study, and the benefits that we can get from the study. Thirdly, our efforts were centered on deploying the VR technology to serve the desired goal. For those reasons, we spent quite some time constructing a very specialized survey. The objective of the survey was to help us identify the main problem that has a common interest to neurosurgeons.

An online survey was conducted using the SurveyMonkey [71] platform distributed through different social media from January 1, 2019 to February 28, 2019. The survey was sent to neurosurgery residents, specialists, and consultants from all over the world. The survey investigated different aspects of the available methods that educational programs offer for teaching surgical skills at different institutes, and explored better ways of assessing surgical training performance from the respondents' point of view. Furthermore, the survey was designed to obtain responses concerning the experiences and perceptions of virtual simulation as a training and assessment tool in neurosurgery, as well as to find the gaps in existing neurosurgical training. The collected data from the survey was then analyzed and summarized on graphs. This might help in selecting the needed training tool. Scripting the questions for the survey took us many meetings and discussions. It was an important step to set up our plan. Please refer to Appendix A for a copy of the survey.

Additionally, we built another qualitative questionnaire asking about the use of ergonomics and VR simulation for surgical practice, including six key parameters of analysis:

- The key limitations of current approaches in surgery, with an emphasis in technological support .
- Their experience in the use of technological tools in surgery.
- Their opinion on the potential of Virtual Reality in surgery.
- The ergonomics considerations in surgery with an emphasis on best and worse practice.
- Their own belief for the evolution of emerging technologies and their adoption in surgery.
- Their recommendations for some new processes and actions for the integration of Virtual Reality, simulations, etc. in surgery?

3.1.2 Building the Simulator

Several meetings have been conducted in order to get a consensus on the suggested training environment and the ergonomics attributes that need to be maintained during the surgery. The results of the meetings concluded that open spine surgery would be used. Also, we agreed that the most important ergonomics attributes that residents and surgeons need to be aware of are their neck angle and elbow height related to the table height. According to Ronstrom et al. [18], the appropriate neck angle to be in flexion of 15–25° and adjust the table, so the patient is at elbow level. Please refer to Figure 3.1 and Figure 3.2. To include these principles in the proposed model, we have adopted a roadmap for developing a VR simulation scenario from Sabbagh et al. [72] (Figure 3.3).

Figure 3.1: The surgeon on the left stands with his head at a slight angle of around 15°-20° with right posture. The surgeon on the right has an inappropriate posture with highly flexed neck.

Figure 3.2: The right operating table's height indicated with operating surface at elbow level.

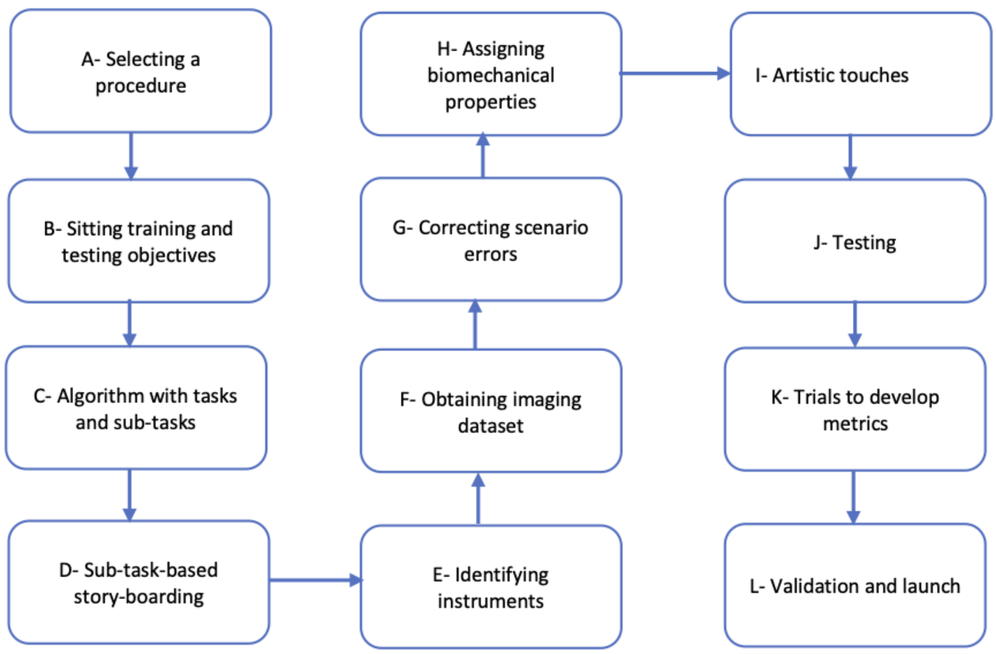


Figure 3.3: Proposed prototype scenario-building roadmap.

To create a surgical ergonomic scenario, first we want the simulator to be realistic enough to instill the user with a sense of comfortability and simultaneously be challenging enough in terms of surgical tasks. The proposed prototype scenario-building roadmap in Figure 3.3 is explained in detail in the following:

A. Selecting a procedure (Figure 3.3.A). In this step, one of the most common procedures in neurosurgery as well as commonly associated with Work Musculoskeletal Disorder(WMSDs) was selected: spinal-cord surgery.

B. Setting training and testing objectives (Figure 3.3.B). In accordance with the main aim of the study, the ergonomics skills were identified: neck angle, elbow height, and hand movements. The training objectives include neurosurgery medical practitioners (consultants, specialists, residents, and interns).

C. Algorithm for the task and sub-tasks (Figure 3.3.C). The task here is to perform a skin opening for the spinal-cord surgery. The sub-task is defined by moving the surgeon close to the patient's table and set her/his elbow height.

The calculation of the elbow height is defined mathematically using the relation below where the center and the radius of a sphere is calculated using 3 points on the surface of the sphere [73]. This can be determined with a simple linear system of 2 equations and 2 unknowns, where the input points are $p_1(x_1, y_1, z_1)$, $p_2(x_2, y_2, z_2)$, $p_3(x_3, y_3, z_3)$ and the unknown are the circle radius and the center of the $c(x_0, y_0, z_0)$. Please refer to Figure 3.4 [74].

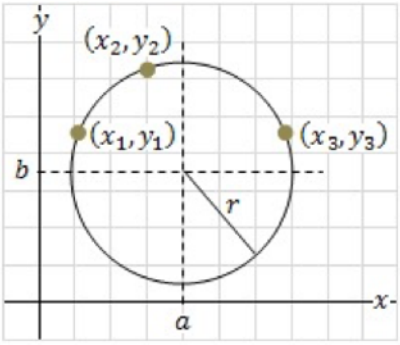


Figure 3.4: Circle passing through 3 points.

The idea is based on the assumption that the 3 points (p_1, p_2, p_3) must belong to a circle with maximum radius of a sphere with center c. Thus, the following conditions must be fulfilled:

- The 3 points (p_1, p_2 and p_3) $\in$ to a sphere with center c.

$$(px_1 - c_x)^2 + (py_1 - c_y)^2 + (pz_1 - c_z)^2 - r^2 = 0 \tag{3.1}$$

$$(px_2 - c_x)^2 + (py_2 - c_y)^2 + (pz_2 - c_z)^2 - r^2 = 0 \tag{3.2}$$

$$(px_3 - c_x)^2 + (py_3 - c_y)^2 + (pz_3 - c_z)^2 - r^2 = 0 \tag{3.3}$$

- The 3 points and the center (p_1, p_2, p_3 and c) $\in$ to the same plane, either $x - y$, $x - z$, or $y - z$ plane.

- Now, let's define the vectors:

$$v_1 = p_2 - p_1 = (v_{1x}, v_{1y}, v_{1z})^T$$

$$v_2 = p_3 - p_1 = (v_{2x}, v_{2y}, v_{2z})^T$$

- The direct expressions for k_1 and k_2 can be derived obtaining:

$$k1 = 0.5 \cdot (v_2^T \cdot v_2) \cdot [(v_1^T \cdot v_1) - (v_1^T \cdot v_2)] / [(v_1^T \cdot v_1) \cdot (v_2^T \cdot v_2) - (v_1^T \cdot v_2)^2] \quad (3.4)$$

$$k2 = 0.5 \cdot (v_1^T \cdot v_1) \cdot [(v_2^T \cdot v_2) - (v_1^T \cdot v_2)] / [(v_1^T \cdot v_1) \cdot (v_2^T \cdot v_2) - (v_1^T \cdot v_2)^2] \quad (3.5)$$

- After determining k1 and k2, the center of the circle is:

$$c_x = p_{1x} + k_1 v_{1x} + k_2 v_{2x} \quad (3.6)$$

$$c_y = p_{1y} + k_1 v_{1y} + k_2 v_{2y} \quad (3.7)$$

$$c_z = p_{1z} + k_1 v_{1z} + k_2 v_{2z} \quad (3.8)$$

D. Sub-task-based story boarding step (Figure 3.3.D). The operator opens the skin and opens the muscle around the spinal processes and suctions the blood exposing the spinal processes in the lumber spine.

E. Identifying the instruments (Figure 3.3.E), the needed instruments are: suction, retractors, 15 blade scalpels, monopolar.

F. Obtaining image dataset (Figure 3.3.F) used in the creation of the 3D environment and the interaction between the operator and the tissues.

G. Correcting scenario errors (Figure 3.3.G) include modifying the errors related to the instruments design in order to meet the reality as possible.

H. Assigning biomechanical properties (Figure 3.3.H) includes adding the haptic feedback and suction and monopolar sounds and effect according to their movements within the wound helps to make the environment close to reality.

I. Artistic touches (Figure 3.3.I) include the imported models to the environment. The models such as the anesthetic operator and the monitoring assistant.

J. Testing step (Figure 3.3.J), we have conducted several meetings with subject matter experts including (biomedical engineers, computer scientists, and surgeons) in order to build and test the created environment.

K. Trials to develop metrics (Figure 3.3.K) include the data analysis according to each operator with the relationship to the ergonomics skills measured.

L. The validation and launch process (Figure 3.3.L). The validation approach applied to the prototype include face and content validity which are mainly based on qualitative data. The design and implementation of the simulator have taken all possible measures to build the environment to the best and meet the training expectation in term of reality of the scenes, the tasks, impact and the reaction.

3.1.3 The VR Simulation Scenario

In this stage of the study, we use the Oculus Quest [75] shown in Figure 3.5. It is an all-in-one gaming system built for VR and no personal computer is required during the run. It has a built-in gyroscope and an accelerometer. The hardware provides room-scale tracking. It comes with touch controllers where the user hands and gestures will appear in VR environment. We used Unity game engine to build and operate the VR system.

Figure 3.5: Oculus Quest.

The 3D wound and surgical instruments are shown in Figure 3.6. These objects and other objects were designed using '***Blender***', which is a free and open-source software toolkit for 3D computer graphics used to build animated movies, visual effects, graphics, 3D printed models, motion graphics, 3D interactive apps, virtual reality, and games [71]. Figures 3.7 and 3.8 show screenshots of instruments and skin design using Blender. With a strong foundation of modeling capabilities, there's also robust texturing, rigging, animation, lighting, and a host of other tools for complete 3D creation.

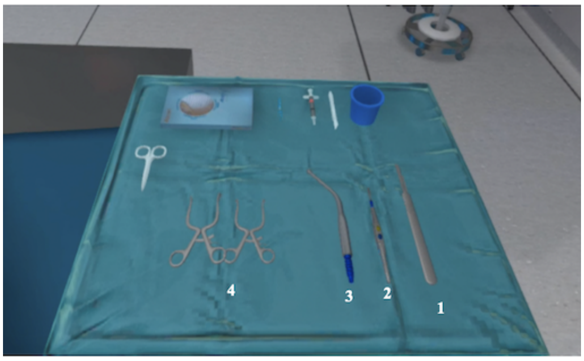


Figure 3.6: Designed surgical instrument, 1- scalpel, 2- suction, 3- monopolar/bipolar, 4- retractors.

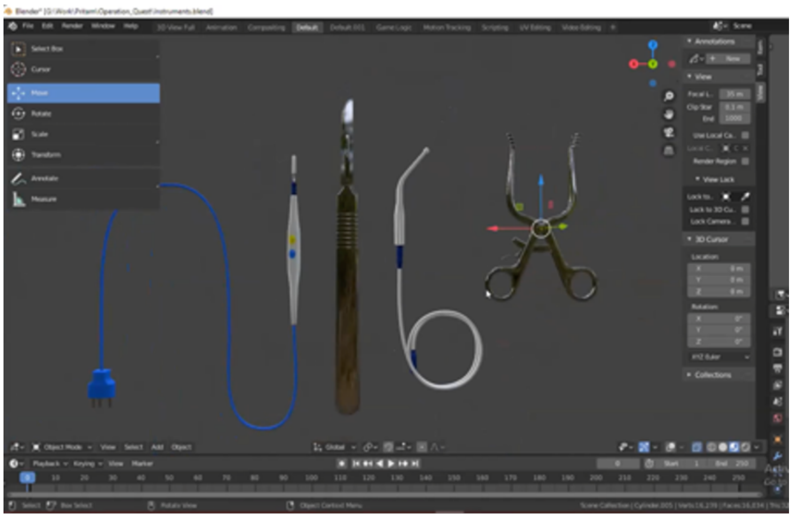


Figure 3.7: Instruments design using Blender.

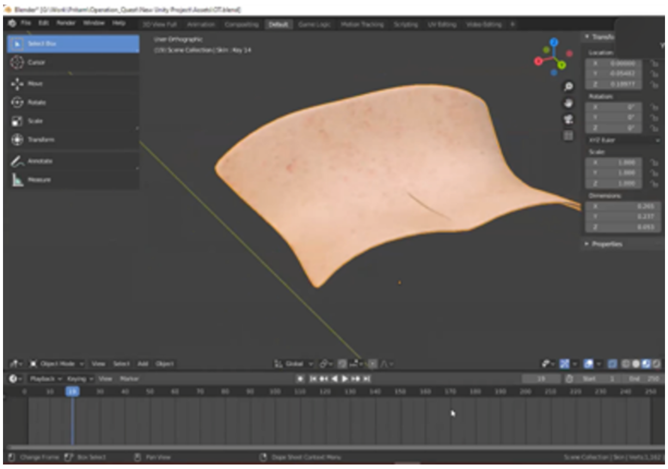


Figure 3.8: Skin design using Blender.

Once the skin, instruments, and other 3D models were built, they were imported to the VR 3D environment in Unity as shown in Figure 3.9. 3D virtual environment is shown in Figure 3.10. The animation of the residents (the user of the simulator) and their interaction with the instruments are controlled by c# script.

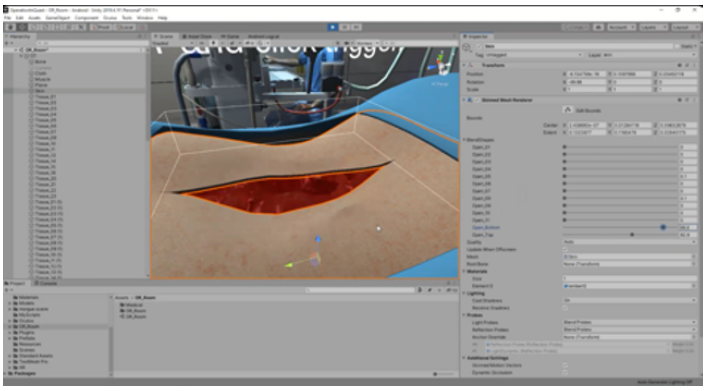


Figure 3.9: Skin cut interaction using Unity platform.

Figure 3.10: 3D virtual environment.

The resident can adjust the table's height using red(lower)/green(higher) buttons. In the simulator (Figure 3.11) [76], the VR headset measures the neck angle using the built-in gyroscope. This data is a set of the following: (1. neck angle- the pitch, 2. elbow height,3. table height, and 4. scalpel position (patient's body height + table height), and 5. hands movements). These data are captured with sampling rate of 1

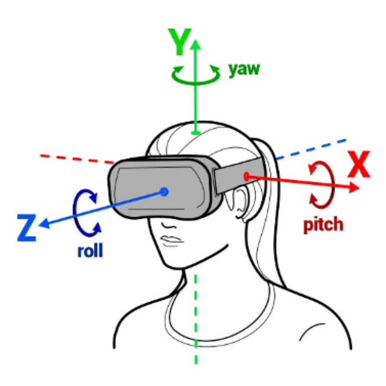


Figure 3.11: Yaw, pitch, roll movements.

set per second and saved in a .csv file for a later analysis. Figure 3.12 explain this process.

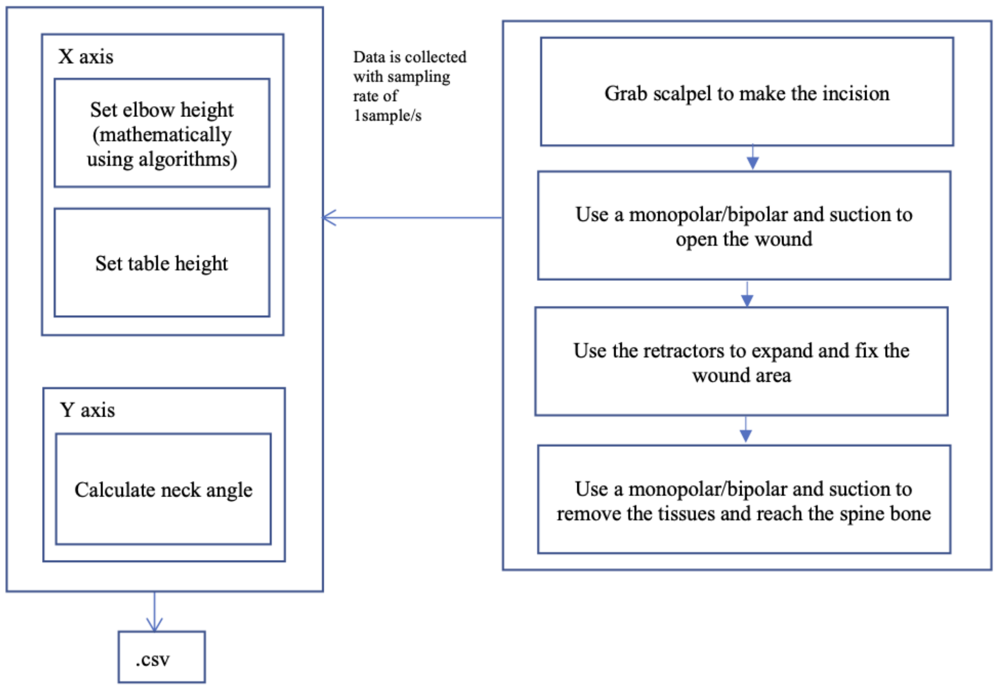


Figure 3.12: System Block Diagram.

The data is collected (the elbow height (c_x, c_y, c_z)) and compared with the scalpel position. The surgical operation requires the resident to do the following:

1- Make the incision cut using a 15-blade scalpel, as shown in Figure 3.13.

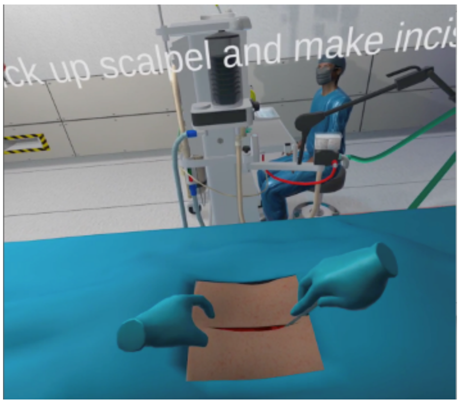


Figure 3.13: The operator making the incision.

2- Using a monopolar/bipolar and suction, the user opens the wound (Figure 3.14).

Figure 3.14: Use a monopolar/bipolar and suction.

3- Using the retractors to expand the wound area and set the opening to a specific dimension as shown in Figure 3.15.

Figure 3.15: Use retractors to expand the wound area.

4- Using a monopolar/bipolar and suction to remove the tissues and reach the spine where the main operation will be conducted.

3.1.4 VR System Architecture

The VR architecture system is shown in Figure 3.16 and has an input which is the head movement and the hand movement that will be the input to the Alternative Word Generator (AWG). The AWG is going to generate the scene and the scene will be projected as video signal or audio signal. The video signal is rendered by the video render and the audio signal is rendered by the audio render and also the measurement of the data is collected in the csv file.

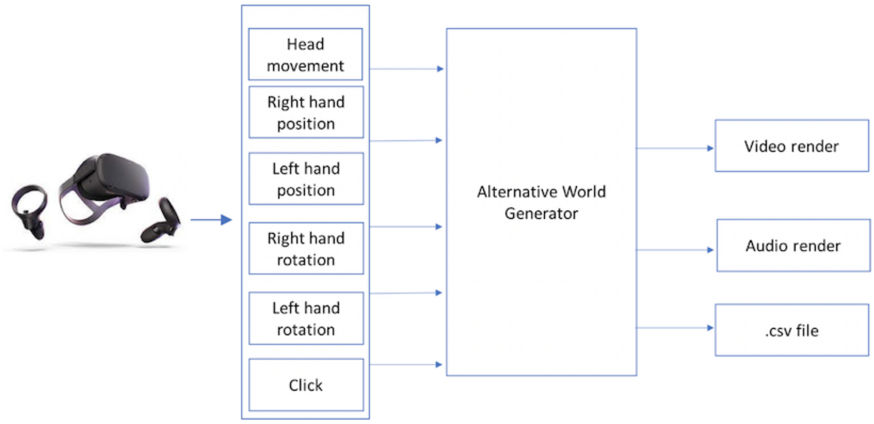


Figure 3.16: VR Architecture system.

3.2 Study 2: Evaluation of Operating Room Compliance based on Ergonomics Skills

This section will explain the second study regarding the evaluation of the compliance of the ergonomics regulation in the OR. The study design and questions will be addressed. The conducted algorithm will be explained. This algorithm has been applied to three different methods combined of machine learning algorithms. The block diagram of each method is described in this chapter.

3.2.1 Study Design

In the second study, we used the Multi-View RGB-D Operating Room (MVOR) dataset [77] contains 738 images for running surgeries. We have performed pre-processing tasks including cleaning the images from any devices appear and any un-necessary images that we don't need. The study is designed as follow:

1. We select pre-processed images from the dataset.
2. We analyze these images using some image processing techniques, which would result in recognition of the good and bad body position and orientation, according to literature we have used (HOG, SVM, YOLO, CNN, and VGG16). This would help in detecting the correct body orientation according to the ergonomics principles.
3. We used HOG and YOLO as two methods to do object detection.
4. We also used SVM and CNN as two methods to do classification of good and bad ergonomics.
5. The third method we used is the pre-trained model VGG-16.
6. Our hypothesis states that using image processing technique would have sufficient and accurate measurement to report on the compliance of the ergonomics regulations in the OR.

The research questions are:

1- Are those images that we select in the OR enough to train a ML model about the body position and orientation?

2- Does this information in question #1 determine if the subject being measured is actually a human?

3- Can the images give some quantitative results (QR) about the status of the people in the OR related to ergonomics?

Where $QR = 1$ for perfect compliance with the ergonomics skills and regulations, and $QR = 0$ with no compliance with the ergonomics skills and regulations.

4- Can we read a stream of images per time unit and update the QR value per time unit $QR(t)$?

Where $QR(1)$ is equal to QR at time=1 and can be written as
$QR(1) = 1$
or $QR(1) = 0$

5- Would it be possible to evaluate the total QR by accumulating QR over time?

$$\text{Overall}(v) = \int_0^t QR(t)dt \tag{3.9}$$

Where v: total values of QR over time from $0 \rightarrow t$, when number of images approaches ∞ and t approaches 0.

6- Can we plot the $QR(t)$ and determine the correlation between QR and (t)?

7- Can we determine the discrete component D value of $QR(i)$ where (i) is the ID of each person in the room and

$$DQR(1) = \text{The } QR \text{ for person \#1}$$

$$\text{Total } DQR \approx \sum_t^T \sum_i^n QR(i)(t) \tag{3.10}$$

Total DQR is total ergonomics in the room including person $1, 2, 3, \ldots, n$ over time $t = 1, 2, 3, \ldots, T$.

3.2.2 Scope of the Study:

The study focuses on neurosurgeons in OR including all health specialists.

Exclusion criteria: Emergency Room.

Inclusion criteria: Operating Room, Spinal surgery.

3.2.3 Algorithm:

- Read a stream of video
- Convert video to a sequence of frames with rate of $1f/s$
- Read each frame
- Identifying objects and recognize human objects using some object detection algorithms (HOG or YOLO).

Assume the ergonomics for a given image EI where

EI (1) = the ergonomics for image #1

EI (2) = the ergonomics for image #2

EI (n) = the ergonomics for image #n

Assume the ergonomics for human subject S is ES where

ES (1) = the ergonomics for human subject S #1

ES (2) = the ergonomics for human subject S #2

ES(m) = the ergonomics for human subject S #m

```
For each image i=0 → n
{for each human subject j=0 → m
          {Assign ergonomics
                       ES(j) = 1 if good
                       ES(j) = 0 if bad
                       ES = ES+ES(j)
           }
          ES = ES/j
          EI=EI+ES
}
EI = EI/i
```

3.2.4 Method#1 HOG+SVM:

This method is processed as follow and shown in Figure 3.17: Compute HOG features for positive images:

- Read files from positive images folder one by one.
- Resize all images to one fixed size.
- Convert the images into single channel RBG to grayscale.
- Calculate HOG features for positive images

Compute HOG features for negative images:

- Read files from negative images folder one by one.
- Resize all images to one fixed size.
- Convert the images into single channel RBG to Grayscale.
- Calculate HOG features for negative images

Add the labels to the positive images and negative images

Train the SVM

- Split the data into training and testing, using 80% for training and 20% for testing.
- Train SVM.
- Evaluate the classifier.

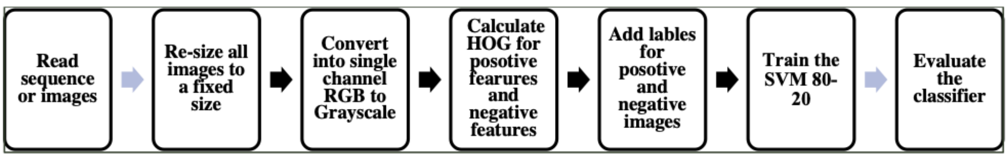


Figure 3.17: HOG+SVM block diagram.

3.2.5 Method#2 YOLO+CNN

YOLO is a very fast and accurate real time neural network (NN) algorithm that can detect objects. We train it and use it in the experiment to detect human body. Once the human object is identified, the images are fed to a CNN stage that classify the images into good or bad ergonomics. Please refer to Figure 3.18.

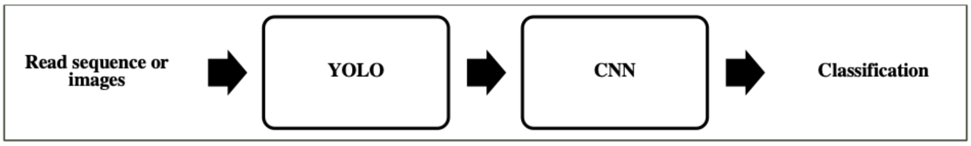


Figure 3.18: YOLO+CNN block diagram.

In this approach, person correct position is identified either by classification or regression technique. Image is taken as input and an array of five elements is taken on the output. This array indicates open person body position.

Number '1' indicates right position while '0' indicates wrong position.

The first element is for the head, the second is for the right shoulder, the third is for the left shoulder, the fourth is for the right elbow, and the fifth is for the left elbow.

We can either use a classification or regression model. It depends on the input data; if we can set a threshold on the input image, then use classification, otherwise we use regression. The next step is to apply CNN and produce the results.

This task is divided into two parts:

- Slope and classification based
- Slope and regression based

3.2.5.1 Slope and Classification based

Creating labels based on poses by computing slopes between some poses (head-neck, left shoulder-left hip, right shoulder-right hip, left elbow- left wrist-left wrist) and using some thresholds to creating binary labels.

```
head_neck_Thr_min = 0
head_neck_Thr_max = 1.5

left_shldr_hip_min = 0
left_shldr_hip_max = 1.5

right_shldr_hip_min = 0
right_shldr_hip_max = 1.5

left_elbow_wrist_min = 0
left_elbow_wrist_max = 1.5

right_elbow_wrist_min = 0
right_elbow_wrist_max = 1.5

batch_size= 32

          head & neck
```

```
calculate the slope for the head_neck
          if slope > neck min and slope < neck max
                   y = 1
          else
                    y = -1

left shoulder and left hip

  calculate the slope for the left_shldr_hip
          if slope > left_shldr_hip min and
              slope < left_shldr_hip max
                    y = 1
          else
                    y = -1

right shoulder and right hip

calculate the slope for the right_shldr_hip
          if slope > right_shldr_hip min and
          slope < right_shldr_hip max
                    y = 1
          else
                    y = -1
```

```
right elbow

calculate the slope for the right_elbow
          if slope > right_elbow min and
          slope < right_elbow max
                    y = 1
          else
                    y = -1

left_elbow

calculate the slope for the left_elbow
          if slope > left_elbow min and
          slope < left_elbow max
                    y = 1
          else
                    y = -1
```

3.2.5.2 Slope and Regression based

Creating labels by computing slopes between some poses (head-neck, left shoulder-left hip, right shoulder-right hip, left elbow- left wrist-left wrist) and using them straight away as targets. A simple CNN model was designed to train the proposed model.

In the case of classification, slopes are calculated and their corresponding labels are provided using threshold values. In the case of regression, only slope values are calculated. Please refer to Figure 3.19 for slope estimation for neck angle and Figure 3.20 for slope estimation for elbow height.

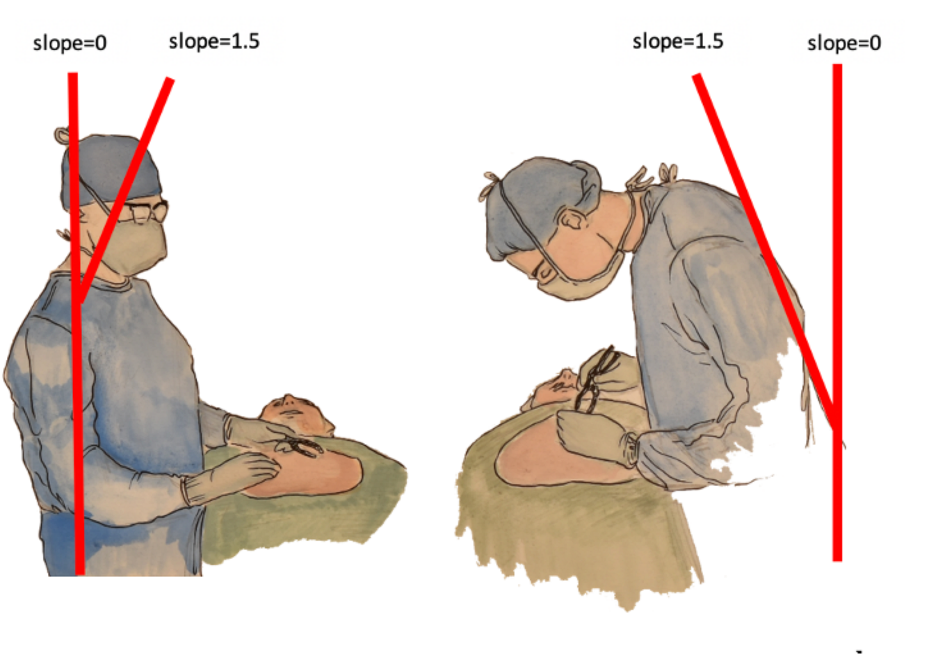


Figure 3.19: Slope estimation for neck angle.

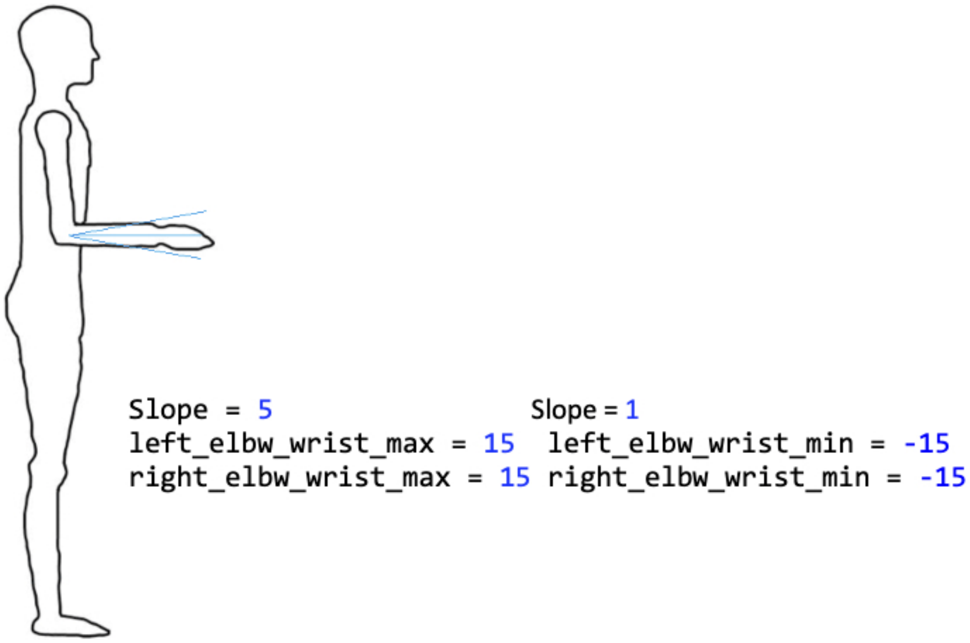


Figure 3.20: Slope estimation for elbow height.

3.3 Method#3 VGG16

VGG-16 is another CNN model that was pretrained of 14 million images with over 1000 datasets. We use it in this experiment to classify images according to ergonomics skills shown in Figure 3.21.

The first step is to find if the image has a human object or not, and give an output of 1/0 for existence if human or non-human.

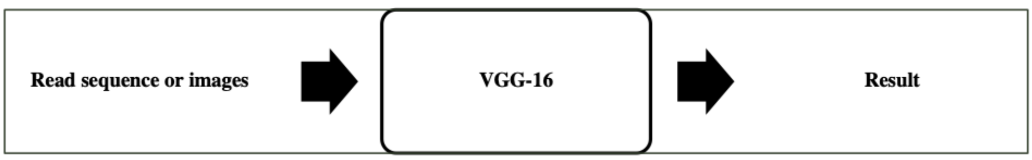


Figure 3.21: VGG-16 block diagram.

If the image has a human object = 1,

no human object = 0.

Then if the human object is standing or working 1/0.

Standing = 1, we assume good ergonomics

Working = 0, we assume bad ergonomics

Chapter 4

Results

This chapter presents the results that were obtained from the two studies that have been implemented according to the methodology in Chapter 3. The first study consists of two phases and the second study consists of three machine learning algorithms that are going to be shown in the second part of this chapter.

4.1 Study 1: Ergonomics Skills Assessment using VR Technology

This section presents the results of the first study including the quantitative and qualitative analysis of the conducted "need based assessment". The conducted experiment is presented as well, including a VR simulator scenario and interaction among the participants. The statistical analysis of the collected data including neck angle, hand movements and rotations among each user and other groups are also given.

4.1.1 Need Based Assessment

As mentioned in chapter 3, an online survey was conducted and distributed to neurosurgery residents, specialists and consultants who are practicing globally. The survey aimed to explore different available methods that educational programs offer for teaching surgical skills at different institutions. The main goal was to identify better techniques to evaluate neurosurgical training performance from the perspective of the participants. In addition, the survey was created to collect feedback on virtual simulation's effectiveness as a training and assessment tool in neurosurgery, as well as to identify gaps in current neurosurgical training.

4.1.1.1 Quantitative Analysis of the Survey

In this questionnaire, 77 neurosurgeons participated in the study from different countries including Saudi Arabia, USA, UK, Pakistan, Egypt, and others. Board-certified surgeons had the greatest representation at 73.6% (56) surgeons, followed by 9.2% (7) senior residents, 9.2% (7) junior residents, 7.8% (6) specialists, and one respondent who didn't mention his education level. Responders represented a total number of 68 males and 7 females (two responders skipped this question). Fifty seven point three percent of the participants (57.33%) worked at tertiary hospitals, 32% of the respondents worked at university hospitals, and the other

10.6% worked at community hospitals. Residency programs are available in the hospitals of 79% of the respondents. This question was asked in order to identify the background of respondents based on their work environments. In our cohort, the top three neurosurgical sub-specialties practiced by the board-certified neurosurgeons were spinal surgery, neuro-oncology, and pediatric neurosurgery. The respondents' characteristics and demographic data are shown in Table 4.1.

When asked about different rehearsal habits, 44% of the respondents said they do rehearsal before operations, while 35% sometimes do, and 19% don't do rehearsal before operations. Regarding which method they practiced for rehearsal, as shown in Figure 4.1, "reviewing medical imaging of the patient" (MRI, CT, ultrasound, X-ray) was practiced by 97% of the respondents, followed by "reviewing the anatomy" at (86%),"discussion" at (77%), "mental rehearsal" with (73%), while the lowest number of respondents (55%) practiced a "review of navigation-generated images." However, most of the respondents (97%) agreed that reviewing medical imaging of the patient (MRI, CT, ultrasound, x-ray) is an essential method of rehearsal. Primarily, it supports medical and surgical treatment planning as well as guiding medical personnel as they insert catheters, maneuver other devices inside the body, or remove blood clots and other blockages.

Referring to the methods that programs offer for teaching surgical skills at the doctors' institutions, an "apprenticeship model (learning by doing)" was most commonly offered (71%), followed by "training on live surgery" (68%), followed by "scheduled surgical lectures" (55%). However, the apprenticeship model is based on the theory of situated learning, which states that a skill must be learned in the

Table 4.1: Respondents' characteristics.

Variables	**Cohort**		**Variables**	**Cohort**	
Gender			**Type of institution**		
Male	90.79%	69	Tertiary Hospital	57.89%	44
Female	9.21%	7	Community Hospital	10.53%	8
	skipped	1	University Hospital	31.58%	24
				skipped	1
Age					
25-34	29.33%	22	**Do you have residency program in your hospital?**		
35-44	26.67%	20	Yes	78.95%	60
45-54	29.33%	22	No	21.05%	16
>55	14.67%	11		**skipped**	1
	skipped	2			
			For how many years have you been practicing at your current level (resident, specialist, or consultant)?		
Educational level		0-1		15.58%	12
Junior resident	9.21%	7	2-5	27.27%	21
Senior resident	9.21%	7	6-10	18.18%	14
Specialist	7.89%	6	11-15	11.69%	9
Board-certified surgeon	73.68%	56	16-20	12.99%	10
	skipped	1	>20	14.29%	11
Region of practice			**What are the two subspecialties you practice most?**		
North America	10.3%	8	Spinal surgery	48.21%	27
South America	2.5%	2	Neuro-oncology	44.64%	25
Europe	7.79%	6	Pediatric neurosurgery	37.50%	21
Asia	70.12%	54	Traumatology	17.86%	10
MENA	5.19%	4	Skull-based surgery	16.07%	9
	skipped	3	Neurovascular surgery	14.29%	8
			Functional neurosurgery	5.36%	3
			Other	Epilepsy surgery Hydrocephalus	

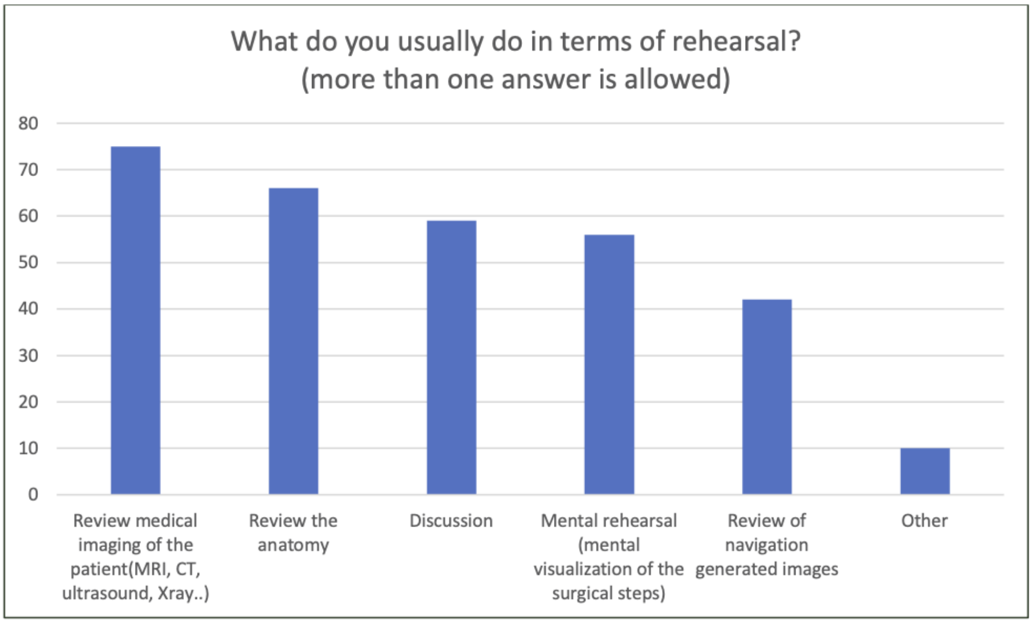


Figure 4.1: Common rehearsal methods.

authentic context where it is to be applied. In terms of defining better ways of assessing surgical training performance, results show that 71% of responses suggested operating on cadavers as a better method, 67% of the respondents suggested deploying virtual reality models, and 51% suggested synthetic models and scheduled surgical lectures.

The questions were designed to discover how much surgeons know about virtual reality. The results showed that 61% of respondents hadn't experienced virtual reality surgical simulation in training, while 90% of total respondents did believe that virtual reality technology can serve surgical training.

When the respondents were asked whether they had explored any of the existing virtual reality neurosurgical simulators, their responses indicated that 57% hadn't explored any kind, while 30% had tried the NeuroTouch (NeuroVR^{TM}) simulator, 13% had tried Surgical Theater's simulator, and 11% had tried the Immersive Touch simulator.

Regarding the preoperative phase, which is an important phase that many doctors may not pay that much attention to, almost all respondents (98%) agreed that there is a gap in existing neurosurgical training in terms of operating room ergonomics skills.

In the patient preparation phase, all three categories (residents, specialties, and board-certified surgeons) recorded a gap in "deciding the incision (tailoring type and location of the incision)" with 70% choosing that answer. When asked about the gap in existing neurosurgical training in the preoperative phase, in order to identify which gaps are common among the majority of respondents, 60% of the residents agreed on "identifying the interface between tumor and brain and use as operating plane for tumor resection", and most of the board-certified surgeons (63%) felt the gap was in "identify anatomic landmarks, functional regions, and major structures". This indicates that board-certified surgeons have more comprehensive thinking toward the existing gaps than the trainees. When the respondents were asked how important the body positioning technique is when compared with the other skills, 89% of them thought that it is essential, as shown in Figure 4.2.

Regarding the gaps in existing neurosurgical training, the respondents were given a wide selection of neurosurgical skills to choose from: scalp incision, bone flap removal, dural opening, open and close scalp incisions, etc. The answers were variable between the different types of surgical skills. Shown in Table 4.2 are the top five skills where respondents felt there were gaps.

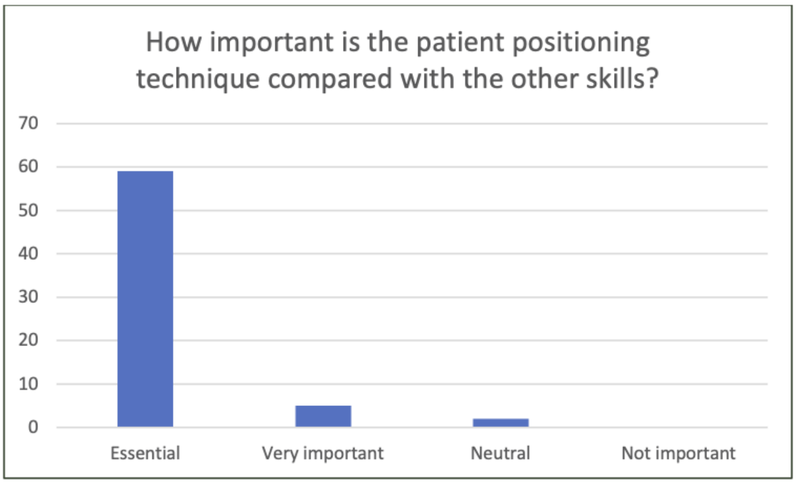


Figure 4.2: Patient positioning technique importance.

Table 4.2: Gaps in existing neurosurgical training in the preoperative phase (Approach).

Where do you feel is the gap in the existing neurosurgical? C-Approach:		
Answer choices	**Responses**	
Identify anatomic landmarks, functional regions, and major structures	57.14%	36
Identify interface between tumor and brain and use as an operating plane for tumor resection	47.62%	30
Perform basic skull base procedures	46.03%	29
Position patients for craniotomy	44.44%	28
Perform resection of pituitary lesions	44.44%	28

4.1.1.2 Qualitative Analysis of the Survey

In this section, we provide the additional insights collected from the focused survey that reached 14 surgeons. The key findings provide additional insights to our investigation and research approach.

In the first focused question, we want to understand the key limitations of current approaches in surgery, with an emphasis on technological support. In Table 4.3, we provide an overview of key limitations.

Table 4.3: Key limitations of current approaches in surgery, with an emphasis in technological support.

Open-Ended Response	**Key issue revealed**	**Contribution to our methodological framework**
Reaching deep structures without causing injury to the outside structures, light during operation, focusing	Reaching deep structures, Light during operation	Light & Reaching of deep structures
Need more time for learning and to the get more chances from the seniors for learning	More time for training	Time for training
High price of surgical simulation devices and lack of availability	High prices of simulation devices	Cost
Some long operations “like Wipple” requires multiple major steps that can be done in other operations but together they make the name, so training and simulation sessions targeting these individual steps build the confidence of this operations “and other operations may share the same step”, the experience and buildup of learning curve	Confidence and experience	Learning curve.
We need more training	Training	Time for training
Need large budget	Budget	Budget resources
Most of the current surgical approaches are based on exploratory procedures where a longer surgical incision is made to look and reach for pathologic or diseased part. Technology may help us in pin pointing the location of bleeders, tumors, cysts, masses, stones etc. It can help in easing up positioning during surgery. Good healing and fewer risks may be achieved with technology.	Easing up positioning	Good healing
Minimally invasive with less exposure; Long learning curve	Less exposure	Long learning curve
IT employees	IT skills	IT skills and employees
There is not enough broadcasting for laparoscopic surgery to outside the OR room so even if someone is not attending can observe the approach. Robotic surgery is not available in most hospitals.	Limited broadcasting	Robotic Surgery
Old generation can’t cope with the new advances especially that relates to technology.	Skills and competencies	Skills

As it is indicated in the overview these are some of the key perceptions of our respondents:

a. Reaching Deep Structures, Light during Operation: It is critical to deploy new methods and more sophisticated approaches to reach deep structures and to improve lighting during operations and realistic representations.

b. More time for training: Time for training seems to be a key limitation factor. From this perspective simulation tools and VR enhanced surgical practice capability combined with ergonomics will add value.

c. High Prices of simulation devices: The development of cost effective simulation environments for surgery is a key requirement.

d. Confidence and Experience: The deployment of technology needs to be based on increased confidence and experience. The availability of simulation environment will allow the development.

e. Training & IT skills: The effective deployment of surgical VR requires enhanced training and development of IT skills. This requires a detailed analysis of training modules and design for integrated curricula.

f. Budget: The required investment in technological tools for surgery is a limitation factor. In these context new approaches bringing into operation fully functional cost efficient environments for simulations and surgical VR or robotics is a significant milestone.

g. Limited broadcasting: Technical difficulties related to connectivity and broadcasting capabilities in operation rooms is also a key factor for investigation and improvement.

h. Skills and competencies: The required skills for technological innovations in surgery need integrated training programs and extensive practice.

In the fifth question, our respondents were requested to summarize their own experience in the use of technological tools in surgery. In their statements, it shows that respondents agreed that there are adequate number of technologies installed, and the operators of those systems have enough skills and competent to work on those new systems. As is shown in Table 4.4 some key areas include: Endoscopic surgeries, Microscopic surgeries, Visualization techniques, Tristappler in powel anastomosis, Laparoscopic Devices, anastamosis, stapling and thermocoagulatory devices. Also, technology adoption related to Utilization, Navigation studies, Endoscopy 3D viewing, VR trials, Laparoscopic Surgery, 3D screens and Robotic Surgery.

In the sixth question, we want to understand the key perceptions of our respondents on their thoughts about the potential of VR in surgery. Some key aspects of their opinions are summarized as follows:

a. Limited Use, Promising Technology: “I didn’t use it before, but I think it would be a wonderful experience and promising field in medicine one day, especially when practicing for the junior physicians and interns to understand the anatomy properly” or “No I didn’t try it, if available it will be soooo beneficial”

b. Concerned attitude: “it has some limitations such as losing the real sensation”

c. Confident positive opinion: “It’s good”

Table 4.4: Responders' experience in the use of technological tools in surgery.

Provide your experience for the use of technological tools in Surgery	
Open-Ended Response	**Key issue revealed**
Endoscopic surgeries in Otolaryngology field shown to be better for visualization when compared to microscopes especially in ear surgeries, which would save operative time, and save skin incisions that would scar and cause pt inconvenience.	• Endoscopic surgeries • Microscopic surgeries • Visualization
Using tristappler or circular stappler in bowel anastomosis	• Tristappler in powel anastomosis
Laparoscopic device	• Laparoscopic Devices
Actually, my answer "as well as others" may be biased in here because some hospitals "including the one I'm working at" is mainly dealing with one company than others so we don't have that much of choices to prefer one product to another, but dealing with Covidine Company in regard of its anastamosis, stapling and thermocoagulatory devices is great and I'm comfortable using them in the field.	• Anastamosis • Stapling and thermocoagulatory devices
Utilizing minimal invasive surgeries will decrease overall complications.	• Utilization
Use of endoscopes, microscopes, navigation studies have helped in our field of neurosurgery.	• Endoscopes • Microscopes • Navigation studies
Endoscopy 3d viewing for difficult access structure	• Endoscopy 3d viewing
VR trials	• VR trials
Not much experience apart from laparoscopic surgery	• Laparoscopic Surgery
Most of our new surgeries depends on new technology including 3D screens, robotic surgery.	• 3D screens • Robotic Surgery

d. Non users: "Never used it before"

e. Awareness build: "We have read about it but still not used it"

f. Advocates: "VR surgery is a great medium to access patients with minimal contact especially in the presence of this pandemic in addition to being able to help patients who are not able to be present in the same place as the surgeon"

Another critical question of our qualitative approach is related to the responders' opinion about ergonomics considerations in Surgery. Below is a summary of the key ideas communicated:

a. Resistance to change: "The main issue with the advanced or technological instruments and approaches in the surgery that it got fought by senior and old physicians that got used to limited approaches and hate the idea of changing their concepts and refusing to give a chance for novel techniques in practice, meanwhile in the other hand it sometimes benefit the patient when there is a pack up approach that is not fully forgotten and vanishes when needed mostly."

b. Key contribution of Ergonomics / Pillar of efficiency: "Ergonomics is a must in surgery especially in Laparoscopic procedures for instance. I have seen in my practice, so far, some examples of applying the ergonomics and stressing on them and the results were excellent on the surgeon, procedural time and result on the patient. Some surgeons were the opposite of not paying attention to them and they had some difficulties."

c. More practice: "It needs more practice."

d. Improve Discomfort: "Surgeon's discomfort has potential negative consequences on surgeon performance and patient outcomes, resulting in lost revenue and surgeon burnout. Improving surgical ergonomics can reduce discomfort and mitigate negative downstream consequences. In the operating room, this includes awareness of body posture and proper operating room setup. Other strategies include a warm-up prior to the first case and taking scheduled breaks during surgery. Outside of the operating room, surgeons can reduce discomfort by improving the ergonomics of their office environment and maintaining good health through routine exercise and stretching. Surgeon educators should teach residents ergonomic principles as well as model their implementation in the operating room.

e. Positioning issues: “Long standing with wrong posturing”

f. Lack of expertise: “As I’ve mentioned, there are not enough expertise in VR.”

g. Core component of success in surgery: “most of our surgeries depends on it and it is efficient”

Additionally, one of our key efforts was to reveal the qualitative aspects of attitude of surgeons on the evolution of emerging technologies and their adoption in Surgery. Below are some of the characteristic opinions that add into the rich picture of our research:

a. We could use many examples to highlight how technology helped us. For example, robotic surgeries used nowadays in oropharyngeal surgeries are saving time and ugly scars in the face to reach a point that is tiny compared to the damage it did when approaching patients surgically, also endoscopic ear surgeries nowadays is the favorable approach with newly graduated physicians with a fascinating outcome when compared to the traditional microscopic surgeries.

b. Its upcoming future...need more learning curve and more teaching centers.

c. Virtual reality whole body anatomy, that surgeon can work on any body part like real patient.

d. Actually, as I'm still a resident and the fact that I haven't worked yet in any robotic surgeries, I lack the knowledge and information needed to discuss this matter.

e. Treat the sport knee

f. Using robotics surgeries would be the near future for most operations.

g. The emergence of new technologies is a wonderful progress. I wish that I have technologies to pinpoint bleeders, tumors exactly on operating table and we can directly manage them without cutting a lot of tissues.

h. I believe in the future it is all about technologies that helps us do less invasive and more effective surgery, but with good exposure and virtual reality for better learning.

i. None

j. Robotic surgery is the best example for future potential in accessing everyone. Technology and medicine should go hand in hand for the present and future.

k. Transferring from conventional thoracotomy to uniportal VATS depends on new technology helped in safe, shorter hospital stay. Robotic surgery is the future.

Finally, our respondents recommended some new processes and actions for the integration of virtual reality, simulations, etc., in surgery.

a. I think the minor surgeries would be a start when implicating the virtual reality and would give the practitioner a good experience when exposed to the same setting intra operatively.

b. Roboting surgery

c. Same answer in previous question

d. One of my recommendations is that if the health committees that approve the residency programs can involve these technologies in the training programs “specially in early years of surgical specialties and their residency programs” that might solve the deficiencies in the residents contributions in OR and will make it much safer for the surgical patients as only experienced surgeons “at least senior residents” can contribute in working in the real operation.

e. None

f. Navigation Scans

g. Before each complicated surgery to make surgeon more confident

h. All residents should have the opportunity and should be included in the residency program.

i. VR may have a role in the future but needs more adoption and practice.

4.1.2 Using the Simulator

The measurements that were collected during the use of the simulator are: neck angle, elbow height, table height (which can be varied upon user control), scalpel position (patient body height + table height) which is captured when the user first touch the skin using the scalpel. Also, the hand movements and rotations are taken during the run of the simulator. These data are taken every second.

The study will start when the user wears the headset and the controllers. He or she will see himself or herself inside a virtual operating room in front of the patient body showing the back area where the surgery will be performed. The user also will see the instrument table on the right side and two buttons on the left. The user will also see the operating instructions on the front side. For the elbow height calculation, the user will be given the instruction; set up the elbow by standing with the right hand straight downwards, click the trigger button once, then bend the arm from the elbow at 90 degrees, and click trigger. Finally bend lower arm further and click trigger (as shown in Figure 4.3). The two buttons on the left side of the user are colored as green and red and are used to adjust the table height as shown in Figure 4.4. The red button is used to lower the table while the green button is used to raise up the table. When the user first touches the skin using the scalpel as shown in Figure 4.5, then, the scalpel position value is registered. Afterward, the user will make the incision cut using the scalpel as shown in Figure 4.6, and meanwhile, all the hand movements, rotations, and other measurements are registered each second.

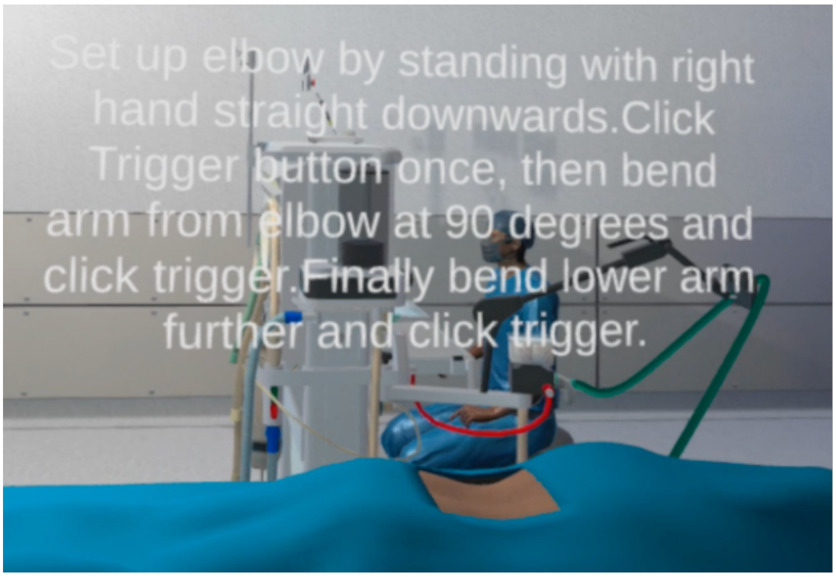


Figure 4.3: Elbow height calculation guidelines.

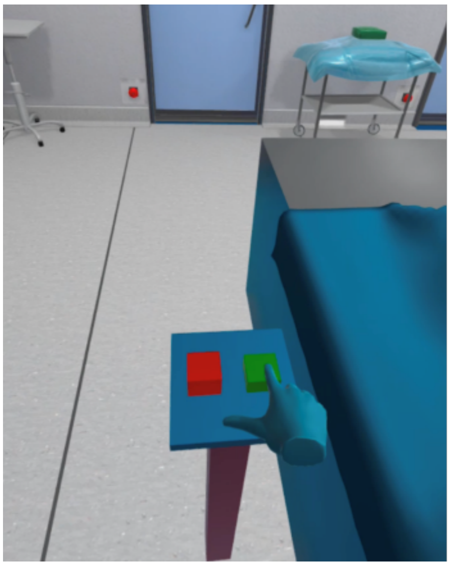


Figure 4.4: Adjusting table height buttons.

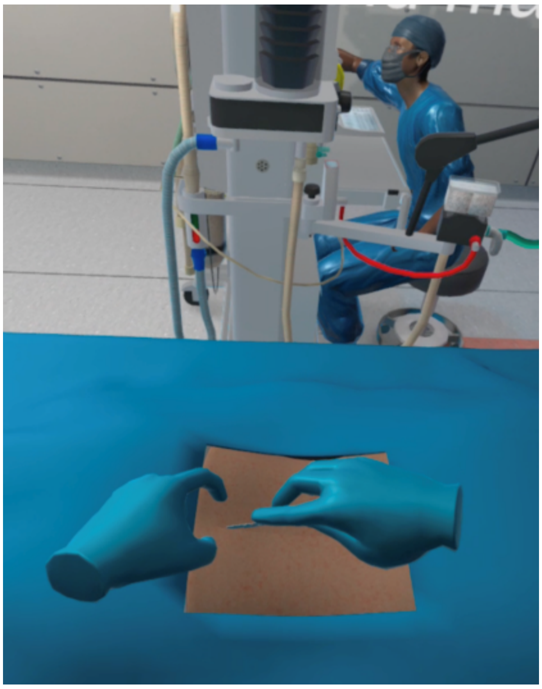


Figure 4.5: Scalpel position calculation.

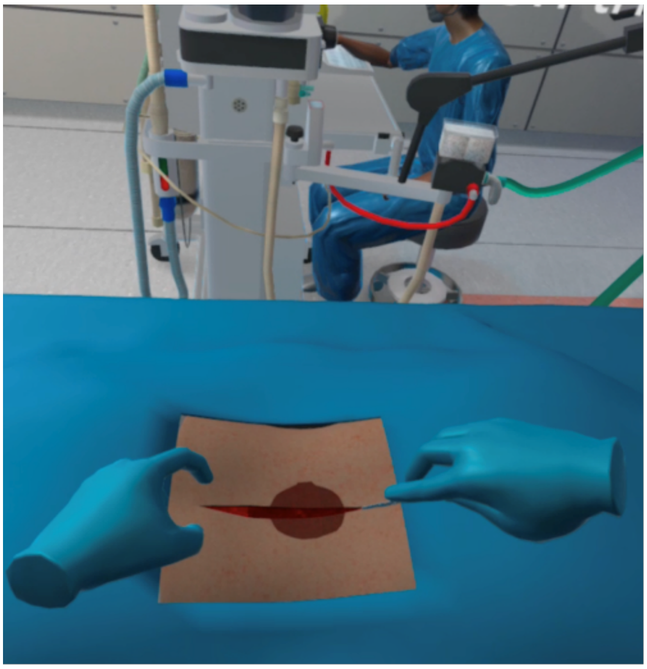


Figure 4.6: Cutting skin complete.

In order to start the study and collect the data from participants, many visits have been done in different hospitals in Makkah and Jeddah cities. The hospitals were: King Abdulaziz University Hospital, King Faisal Specialist Hospital, King Fahad Hospital, AlNoor Specialist Hospital, and National Guard Hospital. Different levels of neurosurgeons have participated in the study including consultants, specialists, residents, and interns. Each participant was asked to wear the VR headset and start the simulated spinal cord surgery. Figure 4.7 shows participants using the simulator.

Figure 4.7: Participants from a) King Fahad Hospital, b) King Abdulaziz University Hospital, c) King Faisal Specialist Hospital, d) National Guard Hospital, and e) Alnoor Specialist Hospital.

In order to proceed with the experiments and evaluation survey, we have applied for ethical approval from the unit of biomedical ethics research committee (IRB reference no. 613-20). The total number of participants was 38. Fifteen (15) of them were consultants (39.47%), 15 were residents (39.47%), 4 were interns (10.52%), and 4 were specialists (10.52%). They were from the following hospitals: King Abdulaziz University Hospital, King Faisal Specialist Hospital, King Fahad Hospital, AlNoor Specialist Hospital, and National Guard Hospital. The users were asked to use the VR headset and to conduct the spine surgery. Each user interacted with the system for 5 minutes following the scenario described in part 2.

4.1.3 Data Analysis for Neck Angle

All the gathered data was analyzed. The differences in the neck angle for the four types of users that employed the system are presented in Figure 4.8 The averages of the descriptive statistics for the data measuring the neck angle for the four types of users are presented in Table 4.5

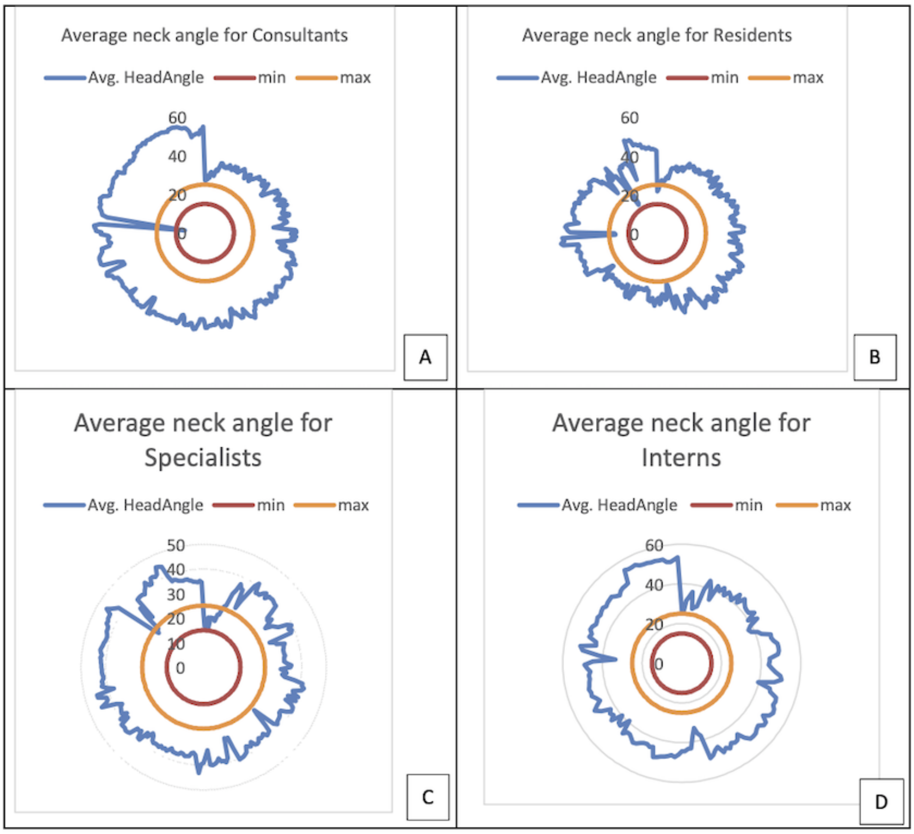


Figure 4.8: Neck angle of A. consultants; B. residents; C. specialists; D. interns.

Table 4.5: Average of descriptive statistics for each type of user.

	Consultants	Interns	Residents	Specialists
Mean	40.97504	45.34816	39.94995	35.86153
Standard Error	0.671811	0.644863	0.690832	0.531334
Median	42.58667	47.15875	41.387	37.46
Mode	40.47267	44.2175	38.71467	38.535
Standard Deviation	9.188041	7.981203	9.921262	7.668814
Sample Variance	88.49642	66.00583	105.9429	72.206
Kurtosis	3.573529	5.167442	0.993583	1.465944
Skewness	-1.35883	-1.85369	-0.74854	-0.67188
Range	45.95933	46.9375	49.04333	39.5575
Minimum	10.22533	10.41	10.19133	13.0225
Maximum	56.18467	57.3475	59.23467	52.58
Confidence Level (95.0%)	1.326918	1.27416	1.362518	1.047708

An analysis of Table 4.5 indicates that, in terms of mean, median and mode, the specialists have the closest values to the ideal range (15-25), followed by residents, consultants and interns. A high value for Kurtosis indicator points out that for interns there are more outliers than for the other types of users. This can be explained by the fact that they are the least experienced and when performing the tasks, they are trying to find the right position through rapid large movements.

To determine if there are statistical differences between the results obtained for each user type, for the neck angles, for each user, the mean of the head angle was computed (Table 4.6). Based on these results, a t-test for the consultants versus the residents (Table 4.7) and for the interns versus the residents (Table 4.8) was performed using the Data Analysis module from Microsoft Excel. As it can be observed from Table 4.7, the two-tail $p > 0.05$, indicating that we cannot reject the null hypothesis (that the means of consultants and residents have no statistical significant difference and $\mu_0 = \mu_1$). Distinctively, in Table 4.8, two-tail $p < 0.05$, indicating that we must reject the null hypothesis (that the means of interns and residents have statistical significant difference and $\mu_0 \neq \mu_1$). Thus, the differences between the residents and the consultants are insignificant statistically and there are statistically significant differences between residents and interns, in terms of head angle, there is a need for advanced training for intern users to reach the necessary level of agronomy that ensures the reduction of injury.

Table 4.6: Mean of head angle obtained by each user.

Criteria	Consultants	Interns	Residents	Specialists
1	29.69957	48.70036	35.01514	40.23226
2	34.41759	35.58516	26.91687	28.59651
3	43.02932	48.28938	27.55603	30.38732
4	37.42358	48.81775	45.58265	44.23004
5	55.819		37.69524	
6	48.44587		40.0125	
7	38.24797		31.09252	
8	18.54827		52.37396	
9	36.69255		50.91987	
10	40.28505		23.85101	
11	43.19073		40.43364	
12	44.47423		48.01839	
13	32.32693		40.17885	
14	60.77973		43.02844	
15	51.24521		56.57416	

Table 4.7: t-Test results for the comparison between Consultants and Residents.

	Consultants	Residents
Mean	40.97504	39.94995
Variance	112.9989	96.2993
Observations	15	15
Pearson Correlation	0.021446	
Hypothesized Mean Difference	0	
df	14	
t Stat	0.277407	
$P(T \leq t)$ one-tail	0.392761	
t Critical one-tail	1.76131	
$P(T \leq t)$ two-tail	0.785522	
t Critical two-tail	2.144787	

Table 4.8: t-Test results for the comparison between Residents and Interns.

	Residents	Interns
Mean	45.34816	35.86153
Variance	42.41406	57.29423
Observations	4	4
Pearson Correlation	0.666144	
Hypothesized Mean Difference	0	
df	3	
t Stat	3.252356	
$P(T \leq t)$ one-tail	0.023702	
t Critical one-tail	2.353363	
$P(T \leq t)$ two-tail	0.047405	
t Critical two-tail	3.182446	

It is worth noting that the close similarity in the results is due to the familiarity with the VR technology. During the experiment, most of the residents were familiar with dealing with the VR device which led them to perform the required task smoothly and in a short time as compared to consultants who had difficulties using the technology.

4.1.4 Data Analysis for Hand Movements and Rotations

After the data was collected, a series of statistical tasks were applied to determine if significant differences exist when we do between t-test. Thus, each type of user (intern, consultant, resident, and specialist) was analyzed individually and in comparison. Two types of hand movement were considered: rotation and position.

4.1.4.1 Interns Rotation Movement

In this case, the statistical indicators for the data obtained is presented in Table 4.9, where P_i indicates the i^{th} intern that took part in the simulation.

Table 4.9: Statistical indicators for the rotation movement of interns.

		P_1	P_2	P_3	P_4	All data
Right_hand_x	Min	0	3.6	0.2	1.3	0
	Max	359.8	358.8	359.8	358.2	359.8
	Average	51.17021	235.9596	153.8723	279.9468	180.2372
	Standard deviation	78.91352	148.4087	163.734	123.4576	158.2894
Left_hand_x	Min	0	0.4	0.1	3.1	0
	Max	359.9	359	359.5	357.2	359.9
	Average	285.5266	182.9351	180.134	265.9862	228.6455
	Standard deviation	137.6423	168.8602	172.5171	142.4514	162.6579
Right_hand_y	Min	4.2	10.2	1.5	13.7	1.5
	Max	181.1	214.6	351.3	214.8	351.3
	Average	33.55	87.91702	75.06277	103.9404	75.11755
	Standard deviation	30.56551	61.26698	61.35257	46.39845	57.55371
Left_hand_y	Min	74.4	14.6	14.2	4.4	4.4
	Max	142.3	201.4	216.3	359.8	359.8
	Average	123.1138	90.1734	100.3436	122.3245	108.9888
	Standard deviation	15.62681	42.73031	40.56546	79.76661	51.97592
Right_hand_z	Min	202.5	242.3	223.3	173.6	173.6
	Max	359.8	353.2	342.2	340.3	359.8
	Average	312.5819	293.5787	276.7	237.7968	280.1644
	Standard deviation	39.02306	30.97953	30.09425	39.73562	44.64676
Left_hand_z	Min	16.1	17.4	13.8	26.8	13.8
	Max	117	100.2	131.9	158.8	158.8
	Average	51.04681	66.21915	74.89362	98.73404	72.7234
	Standard deviation	24.81469	20.71618	31.92074	31.71579	32.56463

By comparing the indicators in group, it can be observed that the differences are not very high, indicating that all the interns have a similar behavior in terms of rotation movement. A histogram for all the participants is presented in Figures 4.9, 4.10, and 4.11 for the x, y, z-axes. As it can be observed from these figures, the movement does not follow a normal distribution fact which implies that the standard t-test to determine the significant differences between types of users is not suited for this case. This is particularly true for the x-axis, where the data tends to have either small or big values with little or no representation in-between.

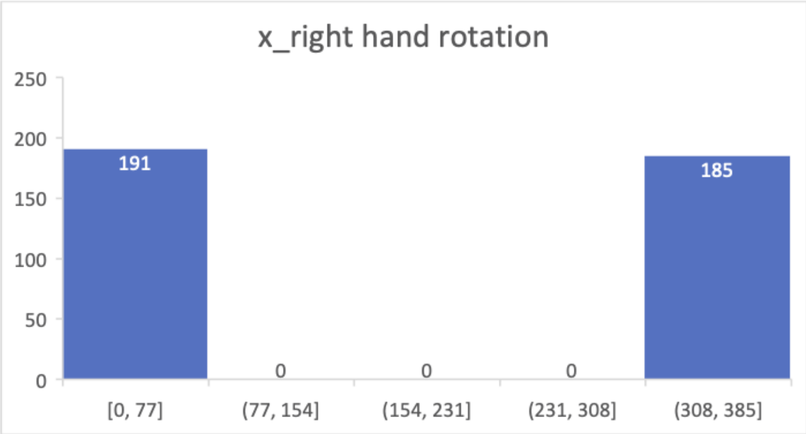


Figure 4.9: Histogram of the right-hand rotation on the x-axis for the interns.

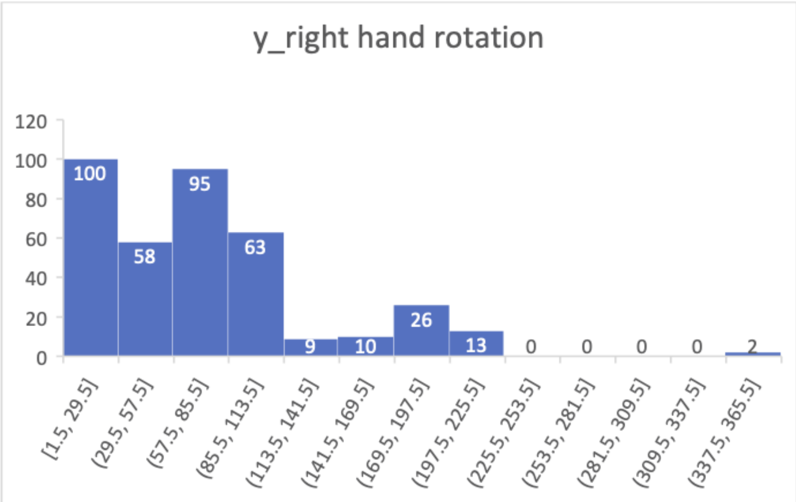


Figure 4.10: Histogram of the right-hand rotation on the y-axis for the interns.

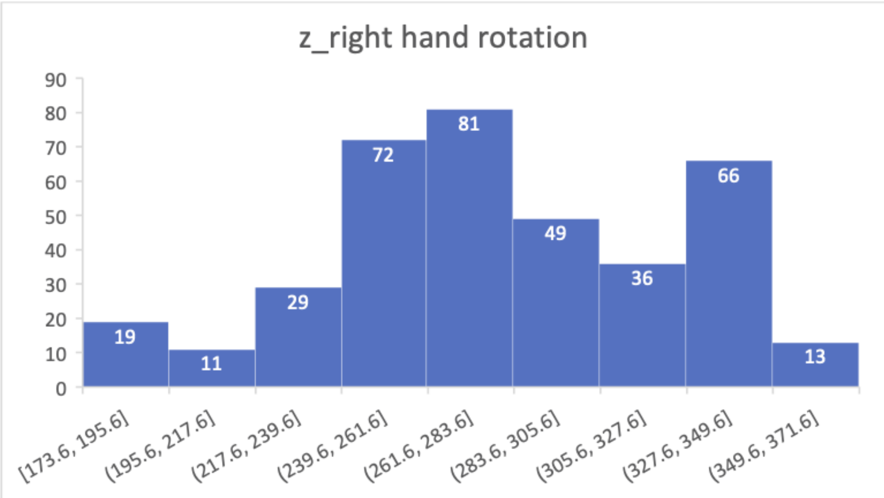


Figure 4.11: Histogram of the right-hand rotation on the z-axis for the interns.

To make a comparison between the different types of users, the Wilcoxon signed ranked test was applied to determine if the median of differences equals 0 and the Freiedman two-way analysis of variance by rank to determine if the distributions are the same.

4.1.4.2 Interns Position Movement

In this case, the statistical indicators for the data obtained is presented in Table 4.10, where P_i indicates the i^{th} intern that took part in the simulation.

Table 4.10: Statistical indicators for the position movement of interns.

		P_1	P_2	P_3	P_4	All data
Right_hand_x	Min	-4.33	-4.63	-4.31	-4.31	-4.63
	Max	-3.4	-3.4	-3.36	-3.4	-3.36
	Average	-3.52936	-3.89457	-3.66989	-3.66064	-3.68862
	Standard deviation	0.241054	0.423411	0.338687	0.278671	0.321189
Left_hand_x	Min	-4.15	-4.67	-4.28	-4.18	-4.67
	Max	-3.36	-3.38	-3.41	-3.36	-3.36
	Average	-3.51309	-3.79021	-3.71	-3.61713	-3.65761
	Standard deviation	0.242811	0.406763	0.306685	0.232793	0.321189
Right_hand_y	Min	0.97	1	1	1	0.97
	Max	1.33	1.45	1.57	1.55	1.57
	Average	1.184255	1.279681	1.219894	1.386383	1.267553
	Standard deviation	0.045068	0.092904	0.102941	0.14437	0.127774
Left_hand_y	Min	1.04	0.96	0.99	1.01	0.96
	Max	1.32	1.38	1.49	1.57	1.57
	Average	1.149362	1.283298	1.238936	1.352872	1.256117
	Standard deviation	0.057358	0.082922	0.093997	0.139982	0.122615
Right_hand_z	Min	1.06	0.93	0.97	1.05	0.93
	Max	1.63	1.78	2.14	1.6	2.14
	Average	1.52117	1.46734	1.540532	1.401702	1.482686
	Standard deviation	0.084292	0.207225	0.242413	0.150001	0.188357
Left_hand_z	Min	1.51	1.16	1.09	1.05	1.05
	Max	1.76	2.13	2.19	2.2	2.2
	Average	1.67883	1.661915	1.699149	1.738936	1.694707
	Standard deviation	0.036155	0.232107	0.221712	0.259153	0.208229

A histogram for all the participants is presented in Figures 4.12, 4.13, and 4.14 for the x, y, z-axes.

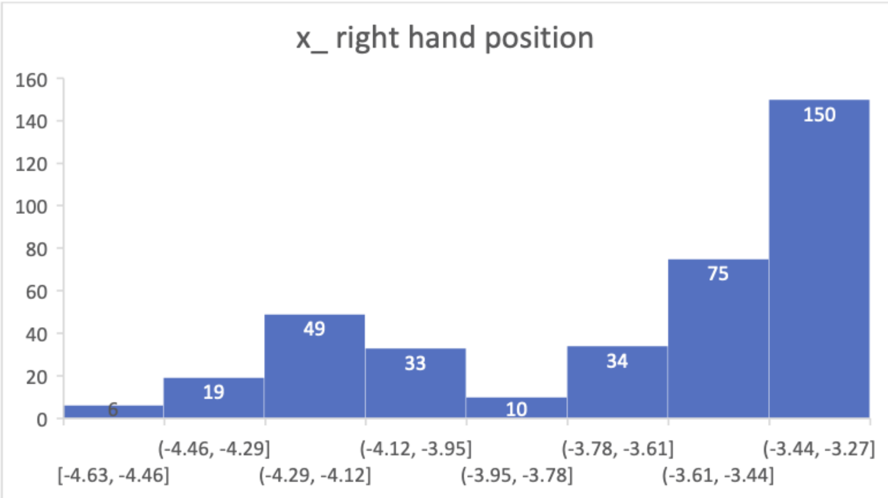


Figure 4.12: Histogram of the right-hand position on the *x*-axis for the interns.

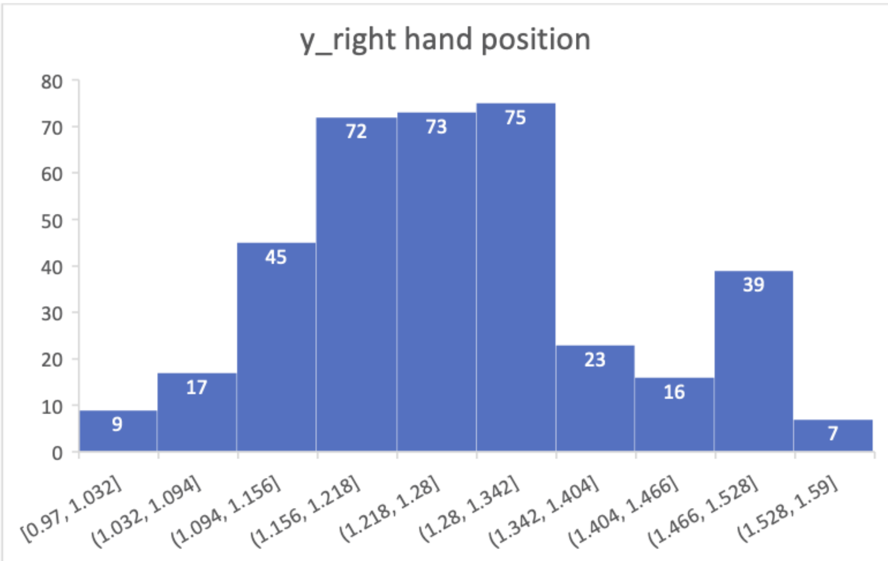


Figure 4.13: Histogram of the right-hand position on the *y*-axis for the interns.

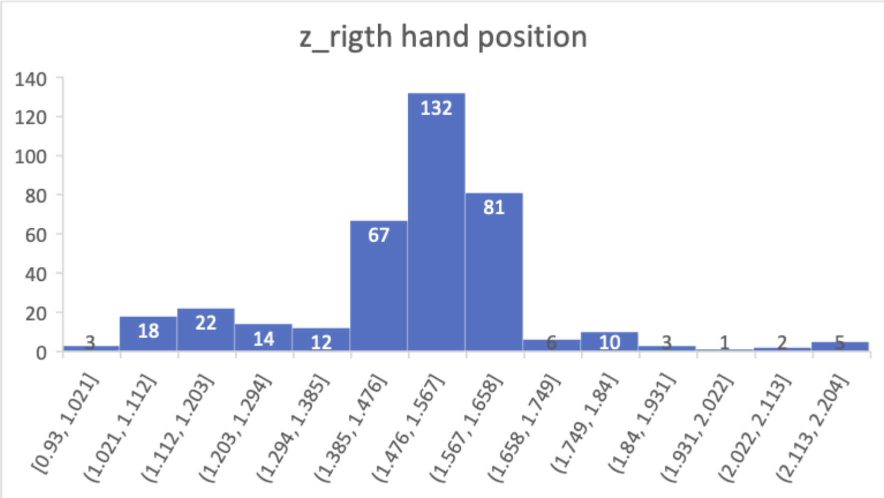


Figure 4.14: Histogram of the right-hand rotation on the z-axis for the interns.

4.1.4.3 Consultants Rotation Movement

In this case, the statistical indicators for the data obtained in presented in Table 4.11, where P_i indicates the i^{th} consultant that took part in the simulation.

Table 4.11: Statistical indicators for the rotation movement of consultants.

		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	All
Right hand x	Min	0.2	0.1	5	0.5	-4.21	1.3	2.8	0.1	4.1	0.3	0.2	-4.21
	Max	359.3	360	359.4	358.5	359.1	359.9	359.4	359.9	357.8	359.7	360	360
	Average	250.5755	173.0872	149.9457	200.117	151.5161	178.083	212.8372	221.9021	41.35745	246.233	206.4234	184.7343
	Stdev	148.2926	169.2318	158.5713	167.4528	169.444	164.2125	159.5838	166.4812	66.95692	156.9686	167.09	165.4703
Left hand x	Min	0.3	0	1.1	0.4	-4.21	0.2	0.5	0.1	1.9	0.6	0.5	-4.21
	Max	359.9	359.6	359.3	359.3	358.2	359.1	359.7	359.4	357.2	359.4	360	360
	Average	263.466	265.3021	23.59574	232.0457	165.8671	155.5287	236.35	114.5415	71.55745	306.8628	314.9702	195.4625
	Stdev	138.3733	150.3646	61.55724	159.5468	170.3865	162.1955	155.9327	157.8463	87.00449	103.1489	80.79549	162.8085
Right hand y	Min	15.4	28.2	27.2	0.4	0.99	0.8	2.3	30.1	10.3	14.3	14.6	0.4
	Max	184.5	203.7	201.8	357.5	205.9	357.2	354.6	195.4	196.9	195.3	198.1	357.5
	Average	78.76596	91.58404	84.22021	70.30957	71.09309	66.45	93.27766	100.8457	78.22872	70.02234	71.9	79.69976
	Stdev	47.73086	36.57491	47.43841	81.33321	61.4435	66.38458	74.98488	40.23857	44.63661	43.39227	39.62859	55.85549
Left hand y	Min	38.2	89.2	5.6	1.5	0.9	20.5	4.5	41.8	0.1	24.6	5.4	0.1
	Max	225.1	195.8	209.8	206.6	215.2	359.4	358.8	118.3	359.4	208.2	161.7	359.4
	Average	132.6298	111.3415	87.15957	95.28936	91.80372	155.4106	99.95319	78.76383	72.65319	103.0447	69.33617	99.76233
	Stdev	37.84966	20.83004	46.27117	34.29494	64.15654	71.79081	59.12258	18.48496	73.49167	34.81061	36.4226	54.47969
Right hand z	Min	2	245.8	245.3	241.9	1.05	0.4	1.6	223.4	0.8	255.9	257.9	0.4
	Max	354.3	343	346.9	355.9	329.4	359	356.2	331.5	359.2	350	354.6	359.2
	Average	283.0649	278.7883	277.5011	292.8011	201.8472	203.8255	306.7883	253.9138	277.4255	295.1766	286.1202	268.8411
	Stdev	42.62112	29.1209	20.6443	29.39549	123.3155	126.9542	56.92874	39.71352	82.3614	25.26285	26.72763	73.96083
Left hand z	Min	26.3	16.2	0.1	7.6	1.05	8.6	2.5	36.3	69.7	68.9	11.6	0.1
	Max	125.5	113.5	359.7	356.4	136.1	120.1	165.8	118.4	206.1	109.6	107.5	359.7
	Average	89.35957	84.25426	63.66064	112.9713	65.56638	61.70851	53.45	86.12021	102.35	91.84043	68.39574	79.97064
	Stdev	22.04515	24.18035	55.42667	77.26423	42.59125	38.22432	37.33574	16.37688	16.65845	8.07435	26.62228	42.06945

A histogram for all the participants is presented in Figures 4.15, 4.16, and 4.17 for the x, y, z-axes.

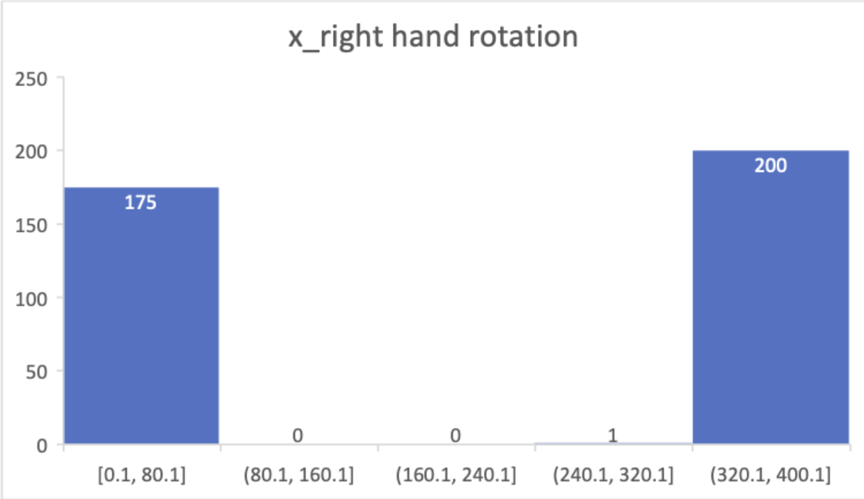


Figure 4.15: Histogram of the right-hand rotation on the x-axis for the consultants.

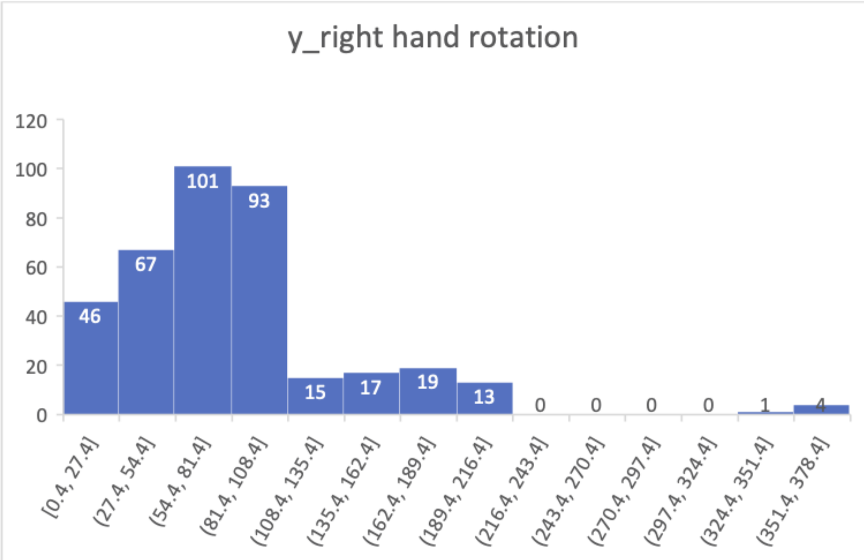


Figure 4.16: Histogram of the right-hand rotation on the y-axis for the consultants.

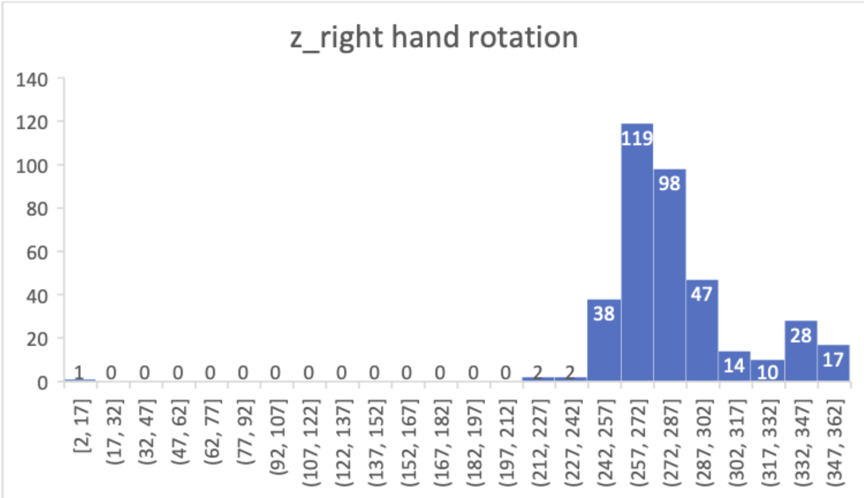


Figure 4.17: Histogram of the right-hand rotation on the z-axis for the consultants.

4.1.4.4 Consultants Position Movement

In this case, the statistical indicators for the data obtained in presented in Table 4.12, where P_i indicates the i^{th} consultant that took part in the simulation.

Table 4.12: Statistical indicators for the rotation movement of consultants.

		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	All
Right hand x	Min	-4.35	-4.32	-4.31	-4.31	-4.29	-4.36	-4.39	-4.38	-4.36	-4.33	-4.27	-4.39
	Max	-3.4	-3.4	-3.39	-3.39	-3.39	-3.4	-3.39	-3.42	-3.42	-3.4	-3.39	-3.39
	Average	-3.64904	-3.56851	-3.76511	-3.50511	-3.66021	-3.70862	-3.8183	-4.18426	-3.84702	-3.58766	-3.73617	-3.73
	Stdev	0.323153	0.234626	0.32616	0.214299	0.317182	0.351221	0.369305	0.264366	0.291532	0.281637	0.227119	0.315336
Left hand x	Min	-4.22	-4.18	-4.21	-4.18	-4.21	-4.56	-4.47	-4.37	-4.32	-4.2	-4.11	-4.56
	Max	-3.39	-3.41	-3.39	-3.39	-3.38	-3.39	-3.43	-3.75	-2.78	-3.44	-3.39	-2.78
	Average	-3.59989	-3.52745	-3.71	-3.53691	-3.59957	-3.72043	-3.80202	-4.10564	-3.88936	-3.61436	-3.73989	-3.71323
	Stdev	0.271628	0.152414	0.318109	0.213939	0.260702	0.403501	0.302045	0.164876	0.3325	0.214238	0.238533	0.315336
Right hand y	Min	0.96	0.95	1.02	0.99	0.98	0.97	0.95	0.97	1.02	0.98	0.99	0.95
	Max	1.33	1.43	1.44	1.43	1.47	1.57	1.68	1.46	1.38	1.24	1.5	1.68
	Average	1.203404	1.236383	1.201702	1.199574	1.244255	1.326915	1.327766	1.331277	1.246596	1.125	1.397766	1.25824
	Stdev	0.081406	0.098732	0.063154	0.081964	0.11978	0.152266	0.15957	0.15644	0.09666	0.058452	0.081176	0.13322
Left hand y	Min	0.98	0.95	0.84	1.02	0.96	0.96	1.03	1.05	0.87	0.99	1.01	0.84
	Max	1.3	1.43	1.26	1.28	1.47	1.58	1.55	1.46	1.44	1.26	1.52	1.58
	Average	1.191596	1.248191	1.175638	1.18117	1.255319	1.311702	1.281064	1.26234	1.193298	1.141809	1.363404	1.236867
	Stdev	0.071592	0.085672	0.087861	0.053518	0.110139	0.179789	0.116448	0.115511	0.125487	0.057342	0.138894	0.126494
Right hand z	Min	1.05	1.07	1.09	1.1	1.05	1.04	1.04	1.07	1.01	1.11	1.12	1.01
	Max	1.6	1.61	1.6	1.73	1.71	2.17	2.12	1.73	1.72	1.87	1.82	2.17
	Average	1.43234	1.463723	1.461489	1.516702	1.441915	1.494149	1.467979	1.456489	1.500213	1.542021	1.557234	1.484932
	Stdev	0.167963	0.127304	0.153237	0.09688	0.203735	0.275019	0.205272	0.218276	0.202617	0.145887	0.117733	0.184258
Left hand z	Min	1.04	1.06	1.13	1.09	1.05	1.04	1.04	1.02	1.22	1.11	1.36	1.02
	Max	2.1	1.79	2.14	2.15	2.15	1.85	2.15	2.16	3.59	2.14	2.14	3.59
	Average	1.630532	1.65234	1.713404	1.714255	1.586702	1.607872	1.669894	1.83	1.872979	1.66766	1.79383	1.703588
	Stdev	0.237647	0.129261	0.215853	0.162226	0.246761	0.227676	0.276458	0.295693	0.495799	0.162537	0.189544	0.271376

A histogram for all the participants is presented in Figures 4.18, 4.19, and 4.20 for the x, y, z-axes.

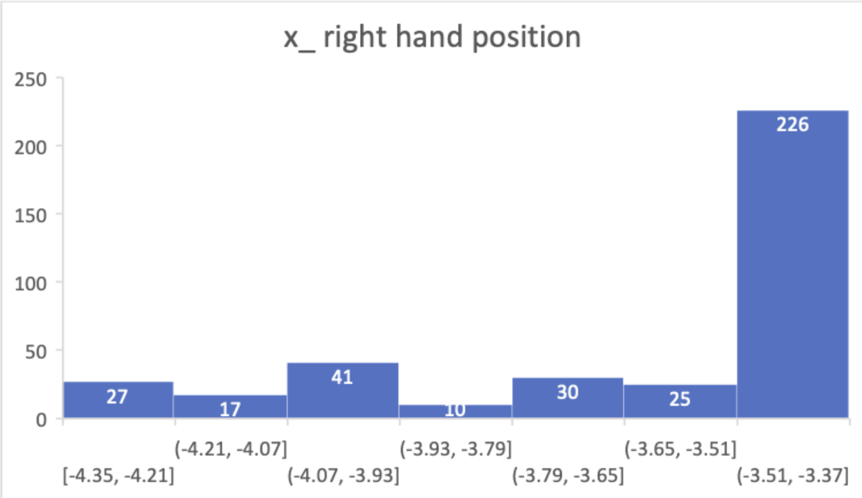


Figure 4.18: Histogram of the right-hand position on the x-axis for the consultants.

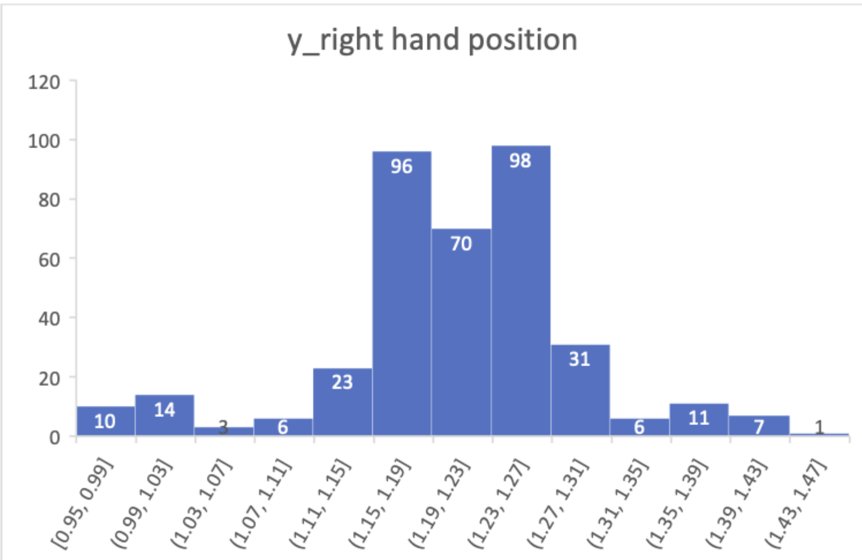


Figure 4.19: Histogram of the right-hand position on the y-axis for the consultants.

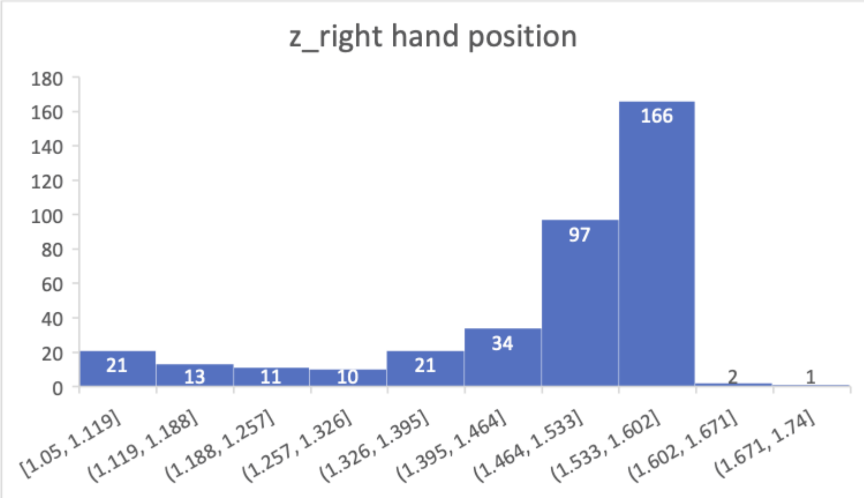


Figure 4.20: Histogram of the right-hand position on the z-axis for the consultants.

4.1.4.5 Residents Rotation Movement

In this case, the statistical indicators for the data obtained in presented in Table 4.13, where P_i indicates the i^{th} resident that took part in the simulation. Compared with other type of user, the test included the highest number of residents (15). Although the minimum and the maximum values are quite similar for all residents, in terms of averages and standard deviation there is quite a high variation.

Table 4.13: Statistical indicators for the rotation movement of residents.

		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	All
Right hand x	Min	0.6	0.4	3.0	0.5	0.3	0.2	1.3	0.6	0.2	2.3	0.0	0.7	1.5	0.7	0.5	0.0
	Max	359.5	359.9	358.4	359.9	359.6	359.6	353.0	359.9	359.7	359.7	359.7	359.7	358.1	359.8	359.7	359.9
	Average	138.0	55.8	301.3	146.9	64.6	153.3	323.0	291.9	172.5	216.9	214.6	144.7	185.0	251.9	208.0	191.2
	Stdev	156.2	106.9	116.7	165.7	116.6	165.9	67.4	120.9	171.7	158.1	156.4	165.1	162.4	156.0	168.0	164.8
Left hand x	Min	0.9	0.0	0.3	0.0	0.2	0.4	0.6	0.1	0.5	1.0	0.0	0.1	0.1	2.1	0.0	0.0
	Max	359.5	359.9	359.8	359.7	360.0	356.5	359.6	359.4	359.9	359.7	359.3	359.5	359.8	360.0	359.9	360.0
	Average	105.6	205.0	296.0	183.5	46.9	34.8	236.3	245.9	168.0	196.9	270.5	175.7	198.9	164.2	305.2	188.9
	Stdev	152.6	170.6	122.7	173.0	107.0	74.9	153.1	154.6	165.1	164.9	133.2	172.5	172.0	168.6	114.3	167.6
Right hand y	Min	10.7	1.4	43.2	7.7	12.2	16.8	16.5	10.1	17.3	10.2	14.7	6.1	16.5	4.7	9.5	1.4
	Max	200.2	359.4	359.8	357.9	193.2	124.3	195.5	207.9	219.6	161.0	356.5	359.7	205.1	192.3	238.1	359.8
	Average	54.1	245.8	131.1	99.1	105.0	59.9	75.8	102.2	84.1	52.1	98.8	143.0	74.6	73.0	116.8	101.0
	Stdev	44.8	134.0	99.4	113.7	48.1	23.5	38.3	53.3	49.2	36.7	69.3	134.9	51.5	47.5	82.2	89.5
Left hand y	Min	0.6	0.1	10.3	7.6	19.3	2.2	0.1	12.0	22.2	34.5	5.6	9.5	16.4	8.1	3.4	0.1
	Max	358.7	359.4	357.9	357.8	357.7	359.7	355.1	255.1	218.8	158.9	356.1	184.2	292.9	200.7	181.7	359.7
	Average	103.8	204.9	170.1	105.1	115.8	82.4	100.9	117.1	113.1	89.2	126.3	93.2	98.5	93.8	108.5	114.8
	Stdev	62.3	147.6	128.7	78.3	61.3	45.1	72.5	39.5	46.6	33.4	58.5	53.3	41.7	46.7	57.2	78.1
Right hand z	Min	0.4	199.7	252.9	196.6	195.0	233.9	214.9	23.2	204.6	272.2	0.8	277.8	232.9	246.1	1.6	0.4
	Max	356.9	352.7	309.7	343.1	308.9	347.8	353.9	350.9	353.2	344.6	358.1	356.5	355.7	353.8	358.8	358.8
	Average	282.1	269.7	270.5	305.2	264.1	274.3	271.0	274.4	276.7	297.9	266.1	319.2	299.8	274.9	310.5	283.8
	Stdev	68.0	24.6	8.5	31.9	20.2	26.6	23.4	39.7	36.2	23.8	63.8	28.1	35.5	22.4	42.9	40.1
Left hand z	Min	0.6	0.6	53.4	17.2	4.0	23.9	10.9	10.6	0.9	1.4	9.7	12.8	9.6	9.3	7.7	0.6
	Max	357.6	111.3	156.8	274.6	142.2	113.0	357.5	348.4	357.7	127.3	357.5	97.0	122.2	115.7	123.4	357.7
	Average	55.1	90.4	96.0	86.8	91.5	60.9	85.7	87.4	85.9	50.2	94.5	69.4	64.3	89.5	79.3	79.1
	Stdev	52.6	16.4	14.7	36.4	32.2	22.0	39.5	38.3	61.2	36.7	88.7	31.7	27.4	14.0	21.9	42.8

A histogram for all the participants is presented in Figures 4.21, 4.22, and 4.23 for the x, y, z-axes.

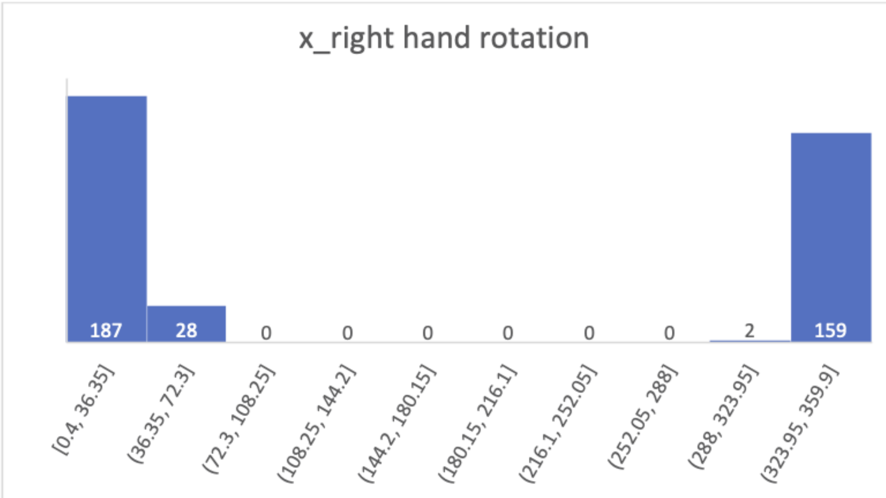


Figure 4.21: Histogram of the right-hand rotation on the x-axis for the residents.

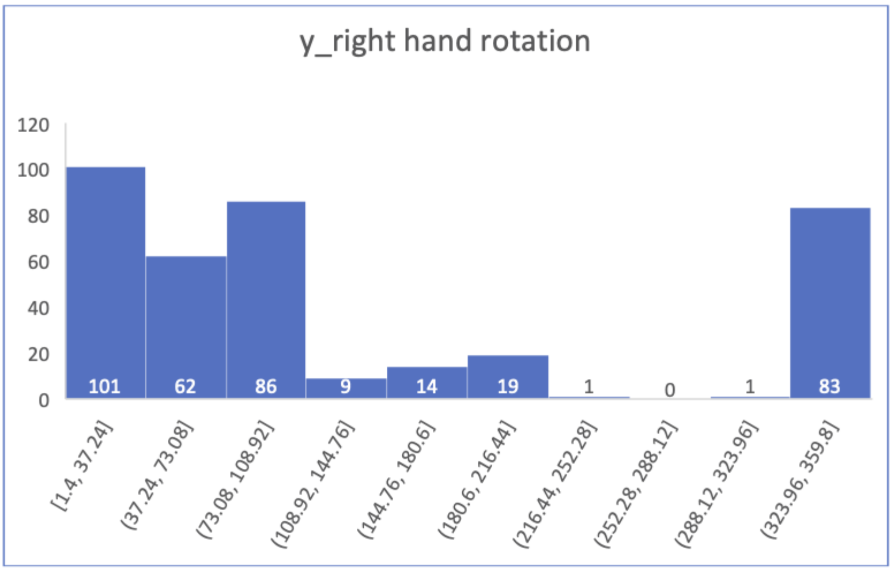


Figure 4.22: Histogram of the right-hand rotation on the y-axis for the residents.

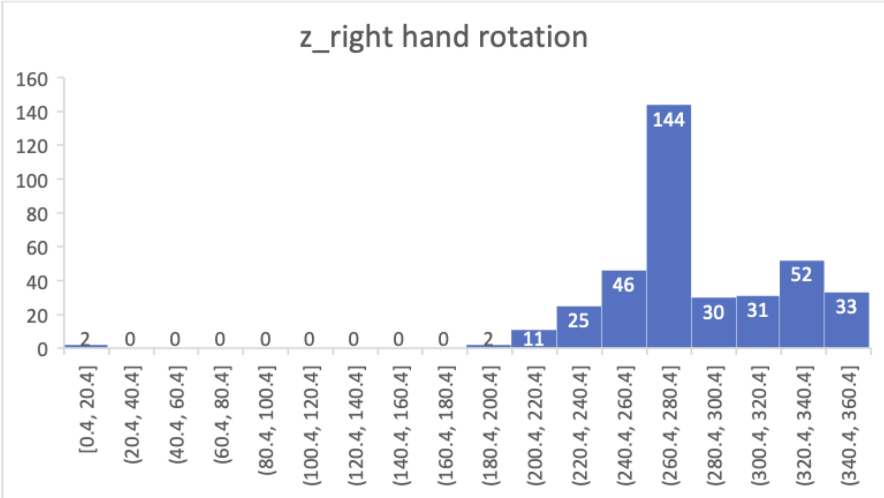


Figure 4.23: Histogram of the right-hand rotation on the z-axis for the residents.

4.1.4.6 Residents Position Movement

In this case, the statistical indicators for the data obtained in presented in Table 4.14, where P_i indicates the i^{th} resident that took part in the simulation.

Table 4.14: Statistical indicators for the position movement of residents.

		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	All
Right hand x	Min	-4.390	-4.300	-4.340	-4.320	-4.410	-4.360	-4.310	-4.410	-4.350	-4.370	-6.250	-4.320	-4.340	-4.330	-4.350	-6.250
	Max	-3.400	-3.400	-3.400	-3.390	-3.380	-3.410	-3.390	-3.410	-3.400	-3.390	-3.380	-3.400	-3.400	-3.410	-3.390	-3.380
	Average	-3.689	-3.926	-3.732	-3.762	-3.928	-3.961	-3.773	-3.729	-3.722	-3.987	-3.914	-3.807	-3.785	-3.737	-3.960	-3.828
	Stdev	0.285	0.181	0.270	0.325	0.340	0.344	0.235	0.332	0.306	0.390	0.647	0.316	0.340	0.303	0.358	0.331
Left hand x	Min	-4.190	-4.310	-4.310	-4.390	-4.280	-4.750	-4.570	-4.190	-4.210	-4.380	-4.300	-4.330	-5.620	-4.190	-4.270	-5.620
	Max	-3.390	-3.400	-3.390	-3.450	-3.390	-3.390	-3.400	-3.400	-2.830	-3.460	-3.390	-3.470	-3.390	-3.410	-3.510	-2.830
	Average	-3.738	-3.999	-3.826	-3.758	-3.878	-3.999	-3.848	-3.662	-3.691	-3.939	-3.686	-3.873	-3.786	-3.714	-3.889	-3.819
	Stdev	0.265	0.234	0.274	0.300	0.301	0.466	0.263	0.270	0.303	0.330	0.280	0.327	0.480	0.270	0.229	0.331
Right hand y	Min	0.970	1.020	0.970	0.980	0.980	0.990	0.960	0.950	0.990	1.020	0.790	0.960	0.890	1.010	0.880	0.790
	Max	1.390	1.660	1.280	1.660	1.510	1.360	1.510	1.530	1.570	1.670	1.680	1.320	1.480	1.490	1.510	1.680
	Average	1.234	1.314	1.203	1.356	1.304	1.235	1.370	1.318	1.426	1.417	1.281	1.207	1.301	1.286	1.249	1.300
	Stdev	0.078	0.110	0.061	0.147	0.114	0.063	0.082	0.121	0.124	0.103	0.174	0.085	0.114	0.095	0.236	0.139
Left hand y	Min	1.040	1.160	1.080	-0.020	1.010	0.950	0.920	1.000	0.410	1.040	0.930	1.170	1.030	1.040	1.040	-0.020
	Max	1.380	1.450	1.250	1.660	1.480	1.390	1.550	1.520	1.600	1.530	1.500	1.310	1.520	1.450	1.540	1.660
	Average	1.206	1.365	1.187	1.428	1.318	1.130	1.307	1.326	1.374	1.359	1.274	1.214	1.282	1.273	1.406	1.297
	Stdev	0.059	0.047	0.039	0.224	0.128	0.096	0.124	0.119	0.170	0.127	0.114	0.035	0.115	0.087	0.093	0.142
Right hand z	Min	1.020	1.070	1.100	1.050	1.060	0.920	1.120	1.030	1.020	1.110	-0.060	1.060	1.100	1.060	1.000	-0.060
	Max	1.700	2.170	2.150	2.170	1.920	1.670	1.780	1.610	1.730	1.610	2.050	2.160	1.640	1.760	1.680	2.170
	Average	1.497	1.722	1.559	1.533	1.481	1.345	1.467	1.416	1.438	1.431	1.325	1.649	1.478	1.504	1.306	1.477
	Stdev	0.158	0.251	0.236	0.288	0.236	0.255	0.166	0.174	0.202	0.135	0.381	0.301	0.144	0.173	0.220	0.254
Left hand z	Min	1.300	1.220	1.460	1.220	1.140	0.040	0.520	1.080	1.100	1.400	1.020	1.220	1.370	1.080	1.180	0.040
	Max	2.170	2.070	2.110	2.000	2.220	2.160	2.100	2.120	2.150	2.140	2.140	1.940	2.340	2.160	2.130	2.340
	Average	1.746	1.746	1.791	1.641	1.695	1.445	1.682	1.595	1.665	1.746	1.574	1.661	1.727	1.720	1.487	1.661
	Stdev	0.197	0.139	0.166	0.187	0.243	0.640	0.298	0.239	0.257	0.176	0.248	0.164	0.221	0.231	0.268	0.285

A histogram for all the participants is presented in Figures 4.24, 4.25, and 4.26 for the x, y, z-axes.

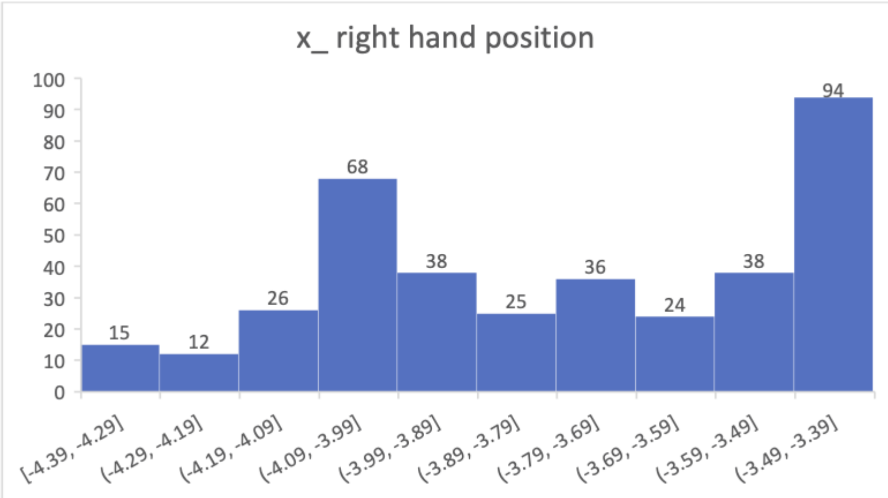


Figure 4.24: Histogram of the right-hand position on the x-axis for the residents.

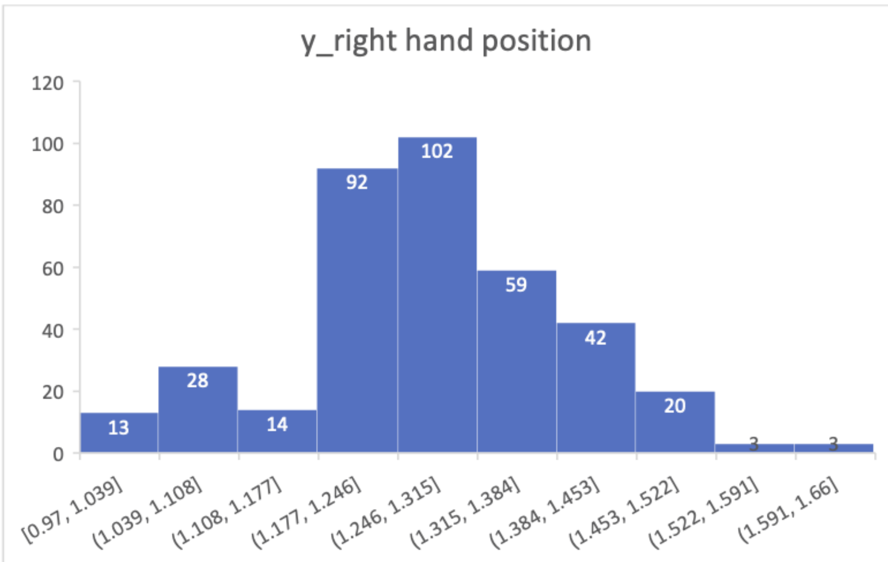


Figure 4.25: Histogram of the right-hand position on the y-axis for the residents.

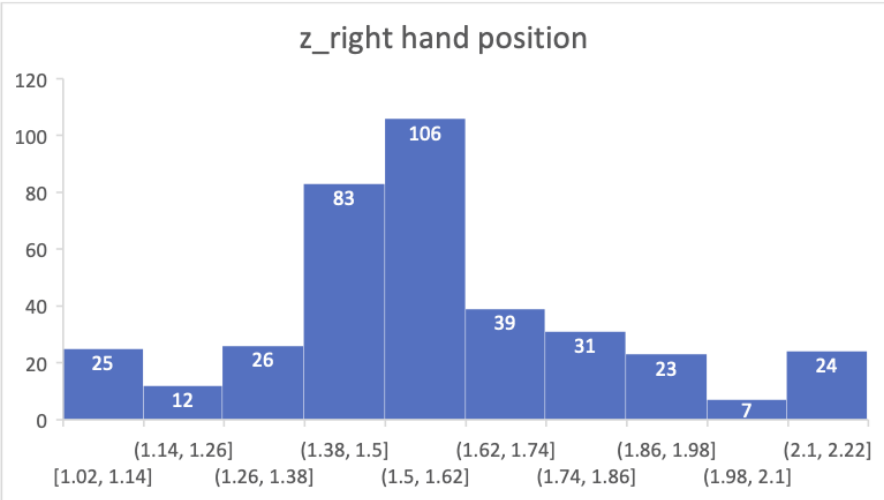


Figure 4.26: Histogram of the right-hand position on the z-axis for the residents.

4.1.4.7 Specialists Rotation Movement

In this case, the statistical indicators for the data obtained in presented in Table 4.15, where P_i indicates the i^{th} intern that took part in the simulation.

Table 4.15: Statistical indicators for the rotation movement of specialists.

		P_1	P_2	P_3	P_4	All data
Right_hand_x	Min	0.3	0.1	5.6	0.3	0.1
	Max	359.7	358.2	357.3	351	359.7
	Average	222.0053	87.4766	286.5064	140.2074	184.0489
	Standard deviation	160.5395	127.9339	130.6519	158.3365	163.443
Left_hand_x	Min	1.4	0	4.6	0.7	0
	Max	359.9	360	358.5	358.3	360
	Average	190.3766	246.7479	274.3117	62.81064	193.5617
	Standard deviation	165.2793	156.7851	136.7855	106.8681	164.2403
Right_hand_y	Min	4.4	9.2	23	22.7	4.4
	Max	197.9	209.5	186.6	207.7	209.5
	Average	85.84255	43.06489	88.19255	90.15745	76.81436
	Standard deviation	51.48984	34.24732	33.3362	51.67308	47.63601
Left_hand_y	Min	8.6	14.2	79.7	9.5	8.6
	Max	355.8	312.1	185.6	182.4	355.8
	Average	112.8128	83.88191	99.68191	88.60957	96.24654
	Standard deviation	68.27775	32.83299	23.64278	43.38121	46.40608
Right_hand_z	Min	230.6	2.2	262.1	11.1	2.2
	Max	353.9	359.2	323.1	343.4	359.2
	Average	273.2383	278.517	278.4702	272.5936	275.7048
	Standard deviation	25.50665	88.99768	12.91934	58.27687	54.92861
Left_hand_z	Min	10.9	0.5	67.2	2.6	0.5
	Max	213	358.4	103.2	139.5	358.4
	Average	86.04362	75.36489	88.46277	76.95532	81.70665
	Standard deviation	24.69964	53.85966	6.547362	30.8223	33.89459

A histogram for all the participants is presented in Figures 4.27, 4.28, and 4.29 for the x, y, z-axes.

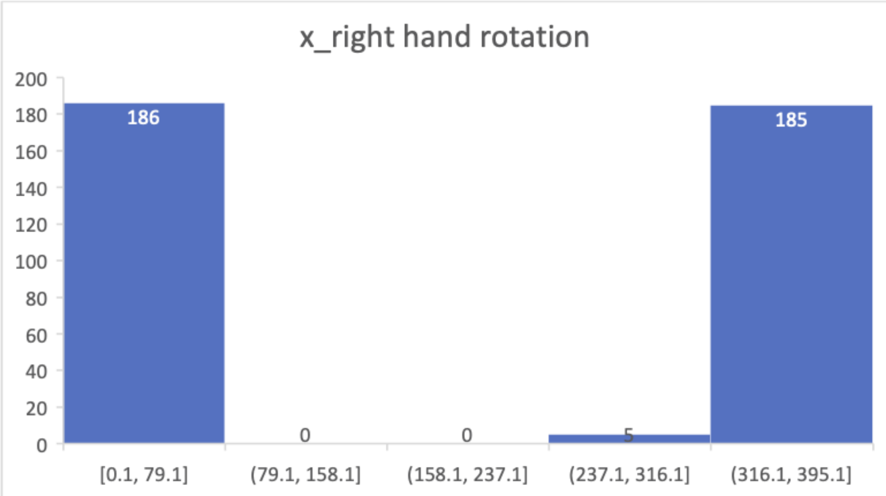


Figure 4.27: Histogram of the right-hand rotation on the x-axis for the specialists.

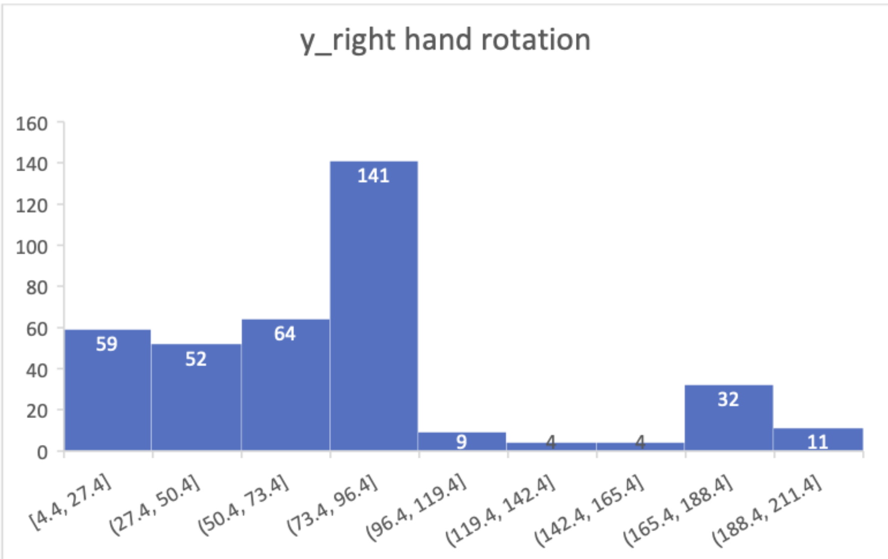


Figure 4.28: Histogram of the right-hand rotation on the y-axis for the specialists.

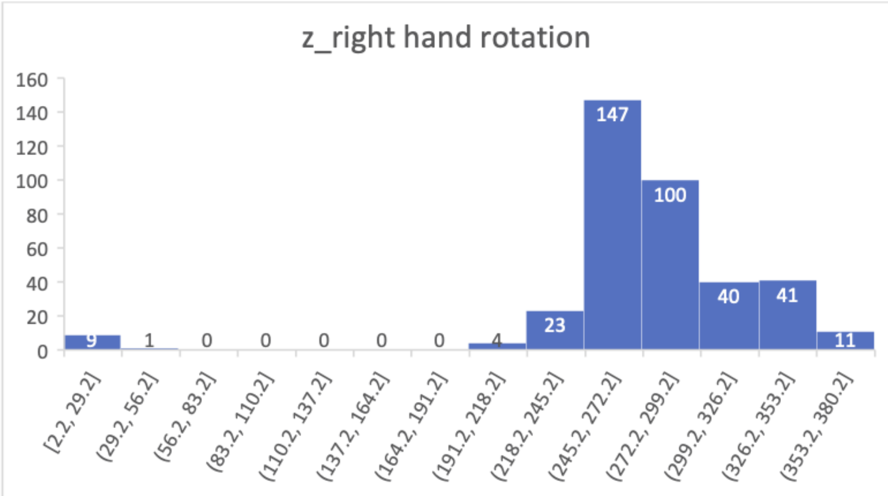


Figure 4.29: Histogram of the right-hand rotation on the z-axis for the specialists.

4.1.4.8 Specialists Position Movement

In this case, the statistical indicators for the data obtained in presented in Table 4.16, where P_i indicates the i^{th} specialist that took part in the simulation.

Table 4.16: Statistical indicators for the position movement of specialists.

		P_1	P_2	P_3	P_4	All data
Right_hand_x	Min	0.3	0.1	5.6	0.3	0.1
	Max	359.7	358.2	357.3	351	359.7
	Average	222.0053	87.4766	286.5064	140.2074	184.0489
	Standard deviation	160.5395	127.9339	130.6519	158.3365	163.443
Left_hand_x	Min	1.4	0	4.6	0.7	0
	Max	359.9	360	358.5	358.3	360
	Average	190.3766	246.7479	274.3117	62.81064	193.5617
	Standard deviation	165.2793	156.7851	136.7855	106.8681	164.2403
Right_hand_y	Min	4.4	9.2	23	22.7	4.4
	Max	197.9	209.5	186.6	207.7	209.5
	Average	85.84255	43.06489	88.19255	90.15745	76.81436
	Standard deviation	51.48984	34.24732	33.3362	51.67308	47.63601
Left_hand_y	Min	8.6	14.2	79.7	9.5	8.6
	Max	355.8	312.1	185.6	182.4	355.8
	Average	112.8128	83.88191	99.68191	88.60957	96.24654
	Standard deviation	68.27775	32.83299	23.64278	43.38121	46.40608
Right_hand_z	Min	230.6	2.2	262.1	11.1	2.2
	Max	353.9	359.2	323.1	343.4	359.2
	Average	273.2383	278.517	278.4702	272.5936	275.7048
	Standard deviation	25.50665	88.99768	12.91934	58.27687	54.92861
Left_hand_z	Min	10.9	0.5	67.2	2.6	0.5
	Max	213	358.4	103.2	139.5	358.4
	Average	86.04362	75.36489	88.46277	76.95532	81.70665
	Standard deviation	24.69964	53.85966	6.547362	30.8223	33.89459

A histogram for all the participants is presented in Figures 4.30, 4.30, and 4.30 for the x, y, z-axes.

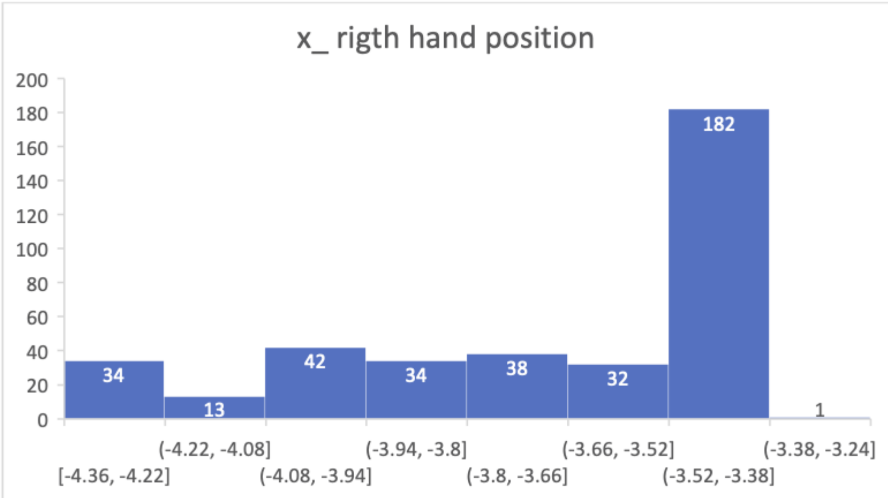


Figure 4.30: Histogram of the right-hand position on the x-axis for the specialists.

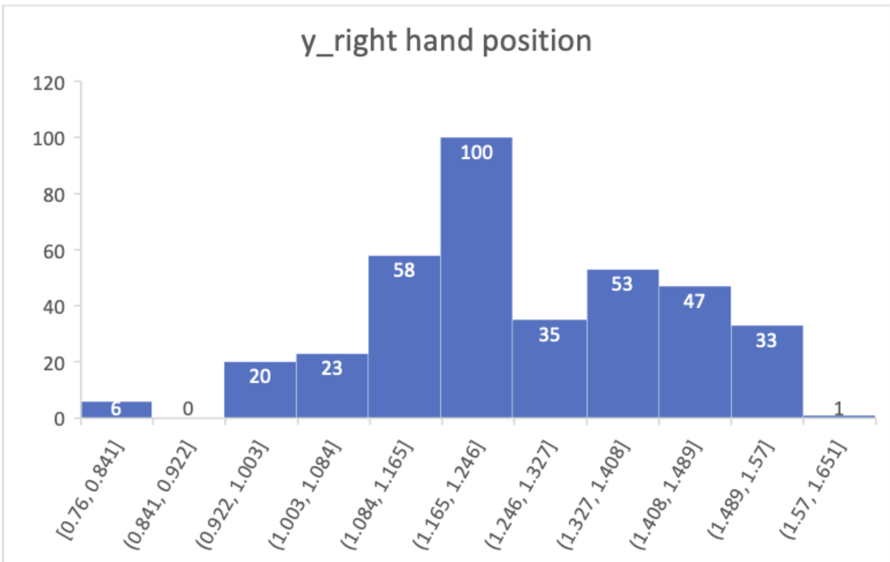


Figure 4.31: Histogram of the right-hand position on the y-axis for the specialists.

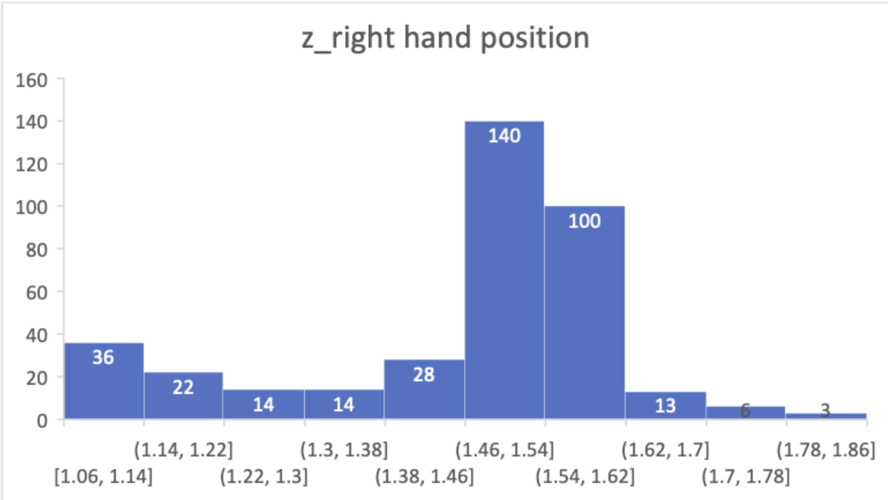


Figure 4.32: Histogram of the right-hand position on the z-axis for the specialists.

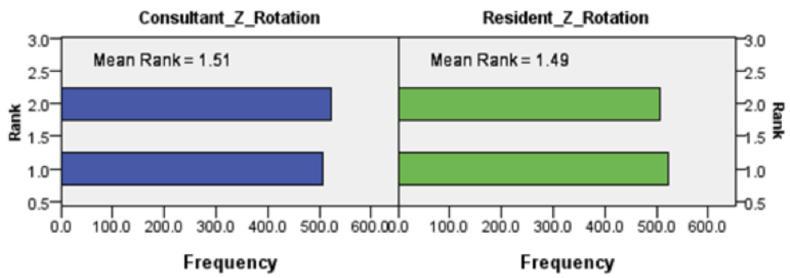
4.1.4.9 Consultants vs Residents

In order to determine if significant differences (in terms of statistical indicators) exist between consultants and residents, the Wilcoxon Signed ranked test (for the median of differences) and the Friedman two-way analysis of variance by rank (for distribution) were applied. The results obtained are listed in Table 4.17.

In terms of distributions, the only similar distribution was obtained for the rotation on the z-axis (Figure 4.33). On the other hand, regarding the median of differences, the rotations on x-axis and z-axis axis and the positions on the z-axis are similar. This indicates that although there are similarities on some aspects (especially when considering the z-axis), overall, the number of rejected hypothesis vs retained hypothesis is 8 vs 4, indicating that there are more differences than similarities.

Table 4.17: Results of the statistics tests.

Movement	Axis	Null Hypothesis	Result	Decision
Rotation	x	The median of differences equals 0	0.352	Retain the null hypothesis
Rotation	x	The distribution is the same	0.015	Reject the null hypothesis
Rotation	y	The median of differences equals 0	0.000	Reject the null hypothesis
Rotation	y	The distribution is the same	0.001	Reject the null hypothesis
Rotation	z	The median of differences equals 0	0.599	Retain the null hypothesis
Rotation	z	The distribution is the same	0.618	Retain the null hypothesis
Position	x	The median of differences equals 0	0.000	Reject the null hypothesis
Position	x	The distribution is the same	0.000	Reject the null hypothesis
Position	y	The median of differences equals 0	0.000	Reject the null hypothesis
Position	y	The distribution is the same	0.000	Reject the null hypothesis
Position	z	The median of differences equals 0	0.227	Retain the null hypothesis
Position	z	The distribution is the same	0.000	Reject the null hypothesis



Total N	1,034
Test Statistic	.248
Degrees of Freedom	1
Asymptotic Sig. (2-sided test)	.618

Figure 4.33: The Friedman two-way analysis of variance by rank for the rotation movement on the z-axis.

4.1.4.10 Specialists vs Interns

In a similar manner to the comparison between consultants and residents, a comparison between specialists and interns was performed using the same statistical tests. The results obtained are listed in Table 4.18.

Table 4.18: Results of the statistics tests.

Movement	Axis	Null Hypothesis	Result	Decision
Rotation	x	The median of differences equals 0	0.653	Retain the null hypothesis
Rotation	x	The distribution is the same	0.877	Retain the null hypothesis
Rotation	y	The median of differences equals 0	0.086	Retain the null hypothesis
Rotation	y	The distribution is the same	0.001	Reject the null hypothesis
Rotation	z	The median of differences equals 0	0.674	Retain the null hypothesis
Rotation	z	The distribution is the same	0.680	Retain the null hypothesis
Position	x	The median of differences equals 0	0.437	Retain the null hypothesis
Position	x	The distribution is the same	0.016	Reject the null hypothesis
Position	y	The median of differences equals 0	0.106	Retain the null hypothesis
Position	y	The distribution is the same	0.794	Retain the null hypothesis
Position	z	The median of differences equals 0	0.509	Retain the null hypothesis
Position	z	The distribution is the same	0.958	Retain the null hypothesis

As it can be observed from Table 4.18, the number of retained hypothesis vs rejected hypothesis is 10 vs 2, indicating that there is compelling evidence that there are many similarities between the specialists and interns. The rejected hypothesis is related to the assumptions that the distributions are the same. When considering the rotation on the y-axis, as it can be observed from Fig 4.10 (corresponding to interns) and Fig 4.28 (corresponding to specialists) that they have a similar shape.

The validation method is applied by self-developed questionnaire (web-based) which contains questions on realism and usefulness of the application. The training system has been evaluated in a questionnaire-based study. After completing the experiment, each participant has to fill some answers regarding their level of expertise and their awareness of ergonomics skills. The participants need to inform in the survey whether they are complaining of any of illnesses related to their work conditions such as back or neck discomfort. After the training all users were asked to fill out a web-based form by rating statements about the training system. A Likert scale ranging from 1 (very easy) to 5 (very hard) was used to record their opinions. The users had the liberty to write text comments and suggestions via the web interface.

Regarding the realism of the simulated spine surgery, the majority of the users mentioned that it was midway between being completely realistic and completely unrealistic. This indicates that the system needs to be improved on term of realism. Please refer to Figure 4.34.

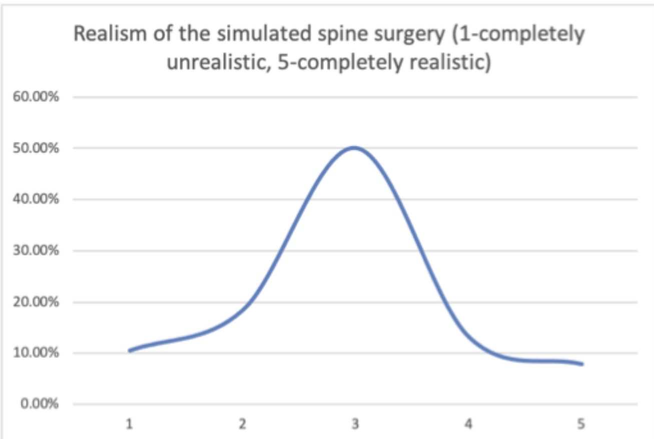


Figure 4.34: Realism of the simulated spine surgery (1-completely unrealistic, 5-completely realistic).

Regarding the usefulness of the VR device during the performed task, nearly 75% of the users agree on the ease of the use of the device. The spine surgery scenario difficulty was also evaluated. Seventy six percent (76%) of the users agreed on the ease of the performed scenario.

4.2 Study 2: Evaluation of Operating Room Compliance based on Ergonomics Skills

This part illustrates the results of the three methods that are utilized in the second study of this dissertation.

4.2.1 Method # 1 HOG+SVM Utilization

The training phase in this case by taking 80% of the images including right pose (positive) and wrong pose (negative), then extract all the features from all the images and label them accordingly, positive or negative. This data was used for the SVM classifier that can classify a given image as positive or negative. Figure 4.35 shows an example of negative body posture. The Results shows 87% accuracy using this method .

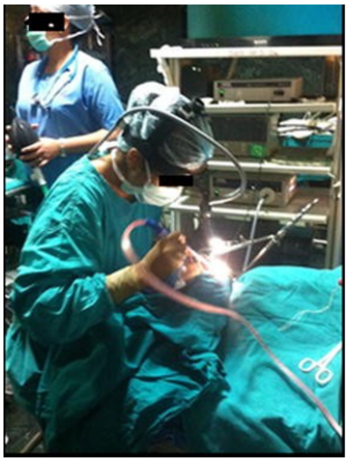


Figure 4.35: Example of negative body posture.

4.2.2 Method # 2 YOLO+CNN Utilization

In this experiment, we can either use a classification or regression model. It depends on the input data; if we can set a threshold on the input image, then use classification, otherwise we use regression. Then CNN is applied. The output of CNN contains five values as five classes, and is given below as you can also see last line of code. Here, the first value is for the neck, the second is for the left shoulder and the third is for the right shoulder, the fourth is for the left elbows and the fifth is for the right elbow. The accuracy of classification model is greater as compared to regression model. Algorithm 1 (classification Model) = 72%. Algorithm 2 (regression Model) = 57%. Figure 4.36 shows example of this method output.

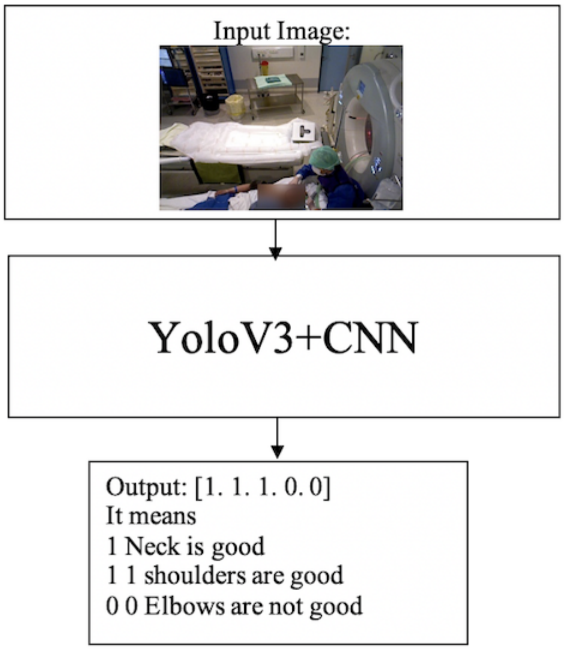


Figure 4.36: Example of YOLO+CNN method output.

4.2.3 Method # 3 VGG16 Utilization

The method is a combination of two phases. The first phase is the detection of humans or non-human. While the second phase will detect if the human is standing or working. The output has two values: 0/1. In the first phase in case of a human, the output is = 1 (positive) where in case of non-human, the output is = 0 (negative). Then, in the second phase, in case of Standing, the output is = 1 (positive) while in case of working, the output is = 0 (negative). The results show 75% accuracy.

Chapter 5

Discussion

In this chapter, we discuss our findings and results related to the studies that have been presented in this dissertation.

5.1 Study 1: Ergonomics Skills Assessment using VR Technology

To proceed with this study, several meetings have been conducted with subject matter experts with the aims to formulate the problem of the research, select specific skills to measure, and find a scope that can be utilized using VR technology. A need-based assessment survey has been conducted online and completed by a large number of neurosurgeons. Those meetings took us up to nine months including setting and editing the survey questions by the team. Results of the survey showed that there are training and rehearsal gaps that, in the past, were never addressed by simulation technologies, such as operating room ergonomics skills, patient positioning, and choosing incisions. Furthermore, it was evident that the need for training in surgical ergonomics skills to improve outcomes exists. The collected data was important to facilitate the creation of a simulation technology prototype.

Regarding the practiced rehearsal method, (97%) of the respondents agreed that reviewing medical imaging of the patient (MRI, CT, ultrasound, x-ray) is an essential method for rehearsal. Fundamentally, it supports medical and surgical treatment planning as well as guiding medical personnel who used to use this technique in the past decades throughout their education. Figure 4.1 shows that most of the rehearsal methods were reviewing medical images, anatomy, mental rehearsal, or discussion. No one provided any comments about simulation or VR.

Referring to the methods that programs offer for teaching surgical skills at the doctors' institutions, an "apprenticeship model (learning by doing)" was most commonly preferred among all other available methods (71%). If someone would report anything related to VR and simulation, it will be in the 10% (other). This might present a gap in the use of VR. When questioned about how much doctors know about VR technology, the majority of about 90% of total respondents believed that VR technology can serve surgical training, while only (57%) had not explored any kind of the existing VR neurosurgical simulators. This is another indication that highlights the need of the VR system for medical personal trainings.

Regarding the preoperative phase, which is an important phase that many doctors may not pay that much attention to, almost all respondents (98%) agreed that there is a gap in existing neurosurgical training in terms of operating room ergonomics skills. In fact, the literature presented in the second chapter firmly endorsed this concept as true by establishing that there is a need to explore the operating room ergonomics skills' challenges.

Figure 4.2 shows that surgeons need non-surgical training as well as surgical skills. As we can see, 60% of the responders consider it essential in their work. Body positioning technique, in particular, is agreed to be of paramount importance in comparison to other techniques. This is due to its difficulty of execution concerning some types of operation, especially those with a cranial based context. According to literature, one of the most important factors when preparing patients for neurosurgical procedures is positioning the head and neck, and proper positioning facilitates optimum surgical approach and visibility. This shows the importance of non-surgical skills.

Table 4.3 gives more motivation for the research. The table highlighted the need for more training and provided comments about the high cost of the training. Many other comments that were provided by the respondents had a great impact on our research.

A few more meetings were conducted in order to get a consensus on the suggested training environment and the ergonomics attributes that are needed to be maintained during the surgery. VR simulator has been implemented and applied by different levels of neurosurgeons in order to compare their measurements and to find any statistical differences among groups. Number of visits to different hospitals have been done to collect as much as possible number of participants.

Figure 4.7 shows some surgeons in different centers while using the simulator. It shows that most of them have very large neck angles. This was clear in Figure 4.8 where the angle should be between 15-25°, but it seems that the angle is above 30°.

For the neck angle analysis, in terms of mean, median and mode, the interns were the most incorrectly positioned. This can be explained by the fact that they are the least experienced and when performing the tasks, they are trying to find the right position through rapid large movements. Moreover, the precipitated interns were 4 in comparison to the residents and specialists who were 15 for each group.

The mean of the head angle was computed for each group to find the statistical differences between each group. Results in table 4.6 showed the differences between the residents and the consultants and are insignificant statistically, while there are statistically significant differences between specialists and interns. This means that there is a need for advanced training on ergonomics for intern users to ensure minimum injury. It is worth noting that the close similarity in the results is due to the familiarity with the VR technology. During the experiment, most of the residents were familiar with dealing with the VR device which led them to perform the required task smoothly and in a short time as compared to the consultants who had difficulties using this kind of technology.

Regarding hand position among all groups, table 4.17 indicated that the number of rejected hypothesis vs retained hypothesis is 8 vs 4, indicating that there are more differences than similarities between residents and consultants. While table 4.18 showed the number of retained hypothesis vs rejected hypothesis as 10 vs 2, indicating that there are many similarities between the specialists and interns. The validation method indicated that the designed simulator was realistic and easy to use and the performed surgery scenario was easy to follow as well.

5.2 Study 2: Evaluation of Operating Room Compliance based on Ergonomics Skills

Three machine learning algorithms have been utilized in order to evaluate surgeons' poses during operations. The output will provide a report measuring the ergonomic skills. The applied algorithms have shown good accuracy percentage. However, the model accuracy could be improved by adding greater number of examples. When we used HOG+SVM, the accuracy was 87%. However, when we used YOLO+CNN, the accuracy was 72% as classification model and 57% as regression model. We also used VGG-16 and the accuracy was 75%.

The results were promising as with larger dataset, we expect YOLO+CNN to give a better accuracy due to the behavior of CNN that needs large number of examples.

Chapter 6

Conclusion

6.1 Conclusion

Ergonomics plays several important roles in the health care area, such as reducing errors and avoiding performance degradation caused by stress and exhaustion. This problem can be fixed by incorporating ergonomics surgical skills' training early in the educational process. In this research, two studies have been developed to address this gap. A VR simulator has been implemented and applied by various levels of neurosurgeons. The number of neurosurgeons that participated in the study could have been larger but the visits to the hospitals were limited due to Covid-19 restrictions. Measurements among all groups have been captured and statistically analyzed. The differences between the residents and the consultants are statistically insignificant, while there are statistically significant differences between specialists and inters. Thus, in terms of head angle, there is a need for advanced training for intern users to reach the necessary level of agronomy that ensures the reduction of injury. Machine learning algorithms have been utilized to estimate surgeons' poses. The accuracy of the results was satisfying to some extent and can be improved if we have a larger dataset. One of the disadvantages that have been noticed in the process of initiating the need-based assessment survey is the long time spent forming and editing the questions.

6.2 Future Work

Future research should focus on the development of objective surgical ergonomics skills and guidelines, as well as the correlation of ergonomics assessments for surgeons with WMSDs. For example, different skills could be targeted and trained using VR technology. Our machine learning algorithm can be used to evaluate the resident's performance while they are in the OR environment. To prevent surgeons from unavoidable, career related injuries, hospitals and residency training programs should design and implement evidence-based ergonomic training programs.

Bibliography

[1] *The American board of surgery* [Online]; Available from: `http://www.absurgery.org`.

[2] Lui, J.T., et al., *Assessing the role of virtual reality training in Canadian Otolaryngology-Head & Neck Residency Programs: a national survey of program directors and residents.* J Otolaryngol Head Neck Surg, 2018. **47**(1): p. 61.

[3] *Health careers* [Online]; Available from: `https://www.healthcareers.nhs.uk`.

[4] Rehder, R., et al., *The role of simulation in neurosurgery.* Childs Nerv Syst, 2016. **32**(1): p. 43-54.

[5] Aggarwal, R., et al., *Training and simulation for patient safety.* BMJ Quality & Safety, 2010. **19**(Suppl 2): p. i34-i43.

[6] Limbrick, D.D., Jr. and R.G. Dacey, Jr., *Simulation in neurosurgery: possibilities and practicalities: foreword.* Neurosurgery, 2013. **73 Suppl 1**: p. 1-3.

[7] Ganju, A., et al., *The role of simulation in neurosurgical education: a survey of 99 United States neurosurgery program directors.* World Neurosurg, 2013. **80**(5): p. e1-e8.

[8] Durkin, E.T., et al., *The impact of work hour restrictions on surgical resident education.* Journal of surgical education, 2008. **65**(1): p. 54-60.

[9] Cohen, A.R., et al., *Virtual reality simulation: basic concepts and use in endoscopic neurosurgery training.* Child's Nervous System, 2013. **29**(8): p. 1235-1244.

[10] Coelho, G., N. Zanon, and B. Warf, *The role of simulation in neurosurgery.* Childs Nerv Syst, 2014. **30**(12): p. 1997-2000.

[11] Zanello, M., et al., *Virtual simulation in neurosurgery: a comparison between pediatric and general neurosurgeons.* Acta neurochirurgica, 2014. **156**(11): p. 2215-2216.

[12] Atesok, K., et al., *Measuring Surgical Skills in Simulation-based Training.* J Am Acad Orthop Surg, 2017. **25**(10): p. 665-672.

[13] Alaraj, Ali, et al., *Virtual reality training in neurosurgery: review of current status and future applications.* Surgical neurology international 2, 2011.

[14] Berguer, R., *The Application of Ergonomics to the General Surgeons' Working Environment.* Reviews on Environmental Health, 1997. **12**(2): p. 99-106.

[15] Soueid, A., et al., *The pain of surgery: pain experienced by surgeons while operating.* International Journal of Surgery, 2010. **8**(2): p. 118-120.

[16] Berguer, R., *Surgery and ergonomics.* Archives of surgery, 1999. **134**(9): p. 1011-1016.

[17] Albayrak, A., et al., *A newly designed ergonomic body support for surgeons.* Surgical endoscopy, 2007. **21**(10): p. 1835-1840.

[18] Ronstrom, C., et al., *Surgical Ergonomics, in Surgeons as Educators.* 2018, Springer. p. 387-417.

[19] Bohm, P.E. and P.M. Arnold, *Simulation and resident education in spinal neurosurgery.* Surgical neurology international, 2015. **6**.

[20] Bürki-Cohen, J., N.N. Soja, and T. Longridge, *Simulator platform motion-the need revisited.* The International Journal of Aviation Psychology, 1998. **8**(3): p. 293-317.

[21] Karaliotas, C., *When simulation in surgical training meets virtual reality.* 2011, Springer.

[22] Djukic, T., V. Mandic, and N. Filipovic, *Virtual reality aided visualization of fluid flow simulations with application in medical education and diagnostics.* Comput Biol Med, 2013. **43**(12): p. 2046-52.

[23] Badash, I., et al., *Innovations in surgery simulation: a review of past, current and future techniques.* Ann Transl Med, 2016. **4**(23): p. 453.

[24] McGaghie, W.C., et al., *Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence.* Academic medicine: journal of the Association of American Medical Colleges, 2011. **86**(6): p. 706.

[25] Seymour, N.E., et al., *Virtual reality training improves operating room performance: results of a randomized, double-blinded study.* Ann Surg, 2002. **236**(4): p. 458-63; discussion 463-4.

[26] Chaer, R.A., et al., *Simulation improves resident performance in catheter-based intervention: results of a randomized, controlled study.* Ann Surg, 2006. **244**(3): p. 343-52.

[27] Pfandler, M., et al., *Virtual reality-based simulators for spine surgery: a systematic review.* Spine J, 2017. **17**(9): p. 1352-1363.

[28] Arora, A., et al., *Virtual reality simulation training in Otolaryngology.* Int J Surg, 2014. **12**(2): p. 87-94.

[29] Bajunaid, K., et al., Impact of acute stress on psychomotor bimanual performance during a simulated tumor resection task. J Neurosurg, 2017. 126(1): p. 71-80.

[30] Vural, F. and E. Sutsunbuloglu, *Ergonomics: an important factor in the operating room.* J Perioper Pract, 2016. **26**(7-8): p. 174-178.

[31] Kant, I.J., et al., *A survey of static and dynamic work postures of operating room staff.* Int Arch Occup Environ Health, 1992. **63**(6): p. 423-8.

[32] Radermacher, K., et al., *Using human factor analysis and VR simulation techniques for the optimization of the surgical worksystem.* Studies in Health Technology and Informatics, 1996. **29**: p. 532-541.

[33] Mirbod, S.M., et al., *Subjective complaints in orthopedists and general surgeons.* Int Arch Occup Environ Health, 1995. **67**(3): p. 179-86.

[34] Li, Y.D., et al., *Musculoskeletal Symptoms in Surgeons: A Review of the Literature. Clinics of Sugery. 2018; 1 (2): 1-4.* 2018, United Prime Publications: `http://unitedprimepub.com` Corresponding Author . . . .

[35] Nguyen, N.T., et al., *An ergonomic evaluation of surgeons' axial skeletal and upper extremity movements during laparoscopic and open surgery.* Am J Surg, 2001. **182**(6): p. 720-4.

[36] Vaisbuc, Y., et al. *Operating room ergonomics: a practical approach for reducing operating room ergonomic hazards.* in *International Conference on Applied Human Factors and Ergonomics.* 2017. Springer.

[37] Yoong, W., et al., *Sticks and stones may break my bones: work-related orthopaedic injuries sustained during obstetrics and gynaecology training*. Journal of Obstetrics and Gynaecology, 2008. **28**(5): p. 478-481.

[38] Berguer, R., et al., *A comparison of surgeons' posture during laparoscopic and open surgical procedures.* Surg Endosc, 1997. **11**(2): p. 139-42.

[39] Berguer, R., W. Smith, and Y. Chung, *Performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery.* Surgical endoscopy, 2001. **15**(10): p. 1204-1207.

[40] Wauben, L.S., et al., *Application of ergonomic guidelines during minimally invasive surgery: a questionnaire survey of 284 surgeons.* Surg Endosc, 2006. **20**(8): p. 1268-74.

[41] Cavanagh, J., et al., *Work environment discomfort and injury: an ergonomic survey study of the American Society of Pediatric Otolaryngology members.* Am J Otolaryngol, 2012. **33**(4): p. 441-6.

[42] McGill, S.M., R.L. Hughson, and K. Parks, *Lumbar erector spinae oxygenation during prolonged contractions: implications for prolonged work.* Ergonomics, 2000. **43**(4): p. 486-493.

[43] Uhrich, M.L., et al., *Assessment of fatigue, monitor placement, and surgical experience during simulated laparoscopic surgery.* Surg Endosc, 2002. **16**(4): p. 635-9.

[44] Bhatnager, V., C.G. Drury, and S.G. Schiro, *Posture, postural discomfort, and performance.* Hum Factors, 1985. **27**(2): p. 189-99.

[45] Bauer, W. and T. Wittig, *Influence of screen and copy holder positions on head posture, muscle activity and user judgement.* Appl Ergon, 1998. **29**(3): p. 185-92.

[46] Seghers, J., A. Jochem, and A. Spaepen, *Posture, muscle activity and muscle fatigue in prolonged VDT work at different screen height settings.* Ergonomics, 2003. **46**(7): p. 714-730.

[47] Turville, K.L., et al., *The effects of video display terminal height on the operator: a comparison of the 15 degree and 40 degree recommendations.* Appl Ergon, 1998. **29**(4): p. 239-46.

[48] Park, A., et al., *Patients benefit while surgeons suffer: an impending epidemic.* Journal of the American College of Surgeons, 2010. **210**(3): p. 306-313.

[49] Korunka, C., et al., *Predictors of a successful implementation of an ergonomic training program.* Applied ergonomics, 2010. **42**(1): p. 98-105.

[50] Mahmud, N., et al., *Ergonomic training reduces musculoskeletal disorders among office workers: results from the 6-month follow-up.* The Malaysian journal of medical sciences: MJMS, 2011. **18**(2): p. 16.

[51] Park, J.Y., et al., *Spine surgeon's kinematics during discectomy, part II: operating table height and visualization methods, including microscope.* Eur Spine J, 2014. **23**(5): p. 1067-76.

[52] Ritter, F.E., et al., *Effects of Varied Surgical Simulation Training Schedules on Motor-Skill Acquisition.* Surg Innov, 2020. **27**(1): p. 68-80.

[53] Rodrigues Armijo, P., et al., *Ergonomics Analysis for Subjective and Objective Fatigue Between Laparoscopic and Robotic Surgical Skills Practice Among Surgeons.* Surgical innovation, 2020. **27**(1): p. 81-87.

[54] Wu, C., et al., *Sensor-based indicators of performance changes between sessions during robotic surgery training.* Applied Ergonomics, 2021. **90**: p. 103251.

[55] Van't Hullenaar, C., et al., *Validation of ergonomic instructions in robot-assisted surgery simulator training.* Surgical endoscopy, 2018. **32**(5): p. 2533-2540.

[56] Ciporen, J., et al., *Crisis management simulation: establishing a dual neurosurgery and anesthesia training experience.* Journal of neurosurgical anesthesiology, 2018. **30**(1): p. 65-70.

[57] De Luca, G., et al., *A multi-procedural virtual reality simulator for orthopaedic training. in International Conference on Human-Computer Interaction.* 2019. Springer.

[58] Teodoro-Vite, S., et al., *A High-Fidelity Hybrid Virtual Reality Simulator of Aneurysm Clipping Repair With Brain Sylvian Fissure Exploration for Vascular*

Neurosurgery Training. Simulation in Healthcare: Journal of the Society for Simulation in Healthcare, 2020.

[59] Yadav, Y.R., et al., *Microneurosurgical skills training.* J Neurol Surg A Cent Eur Neurosurg, 2016. **77**(2): p. 146-154.

[60] Azarnoush, H., et al., *The force pyramid: a spatial analysis of force application during virtual reality brain tumor resection.* Journal of neurosurgery, 2016. **127**(1): p. 171-181.

[61] Pang, Y., et al., *Efficient HOG human detection.* Signal Processing, 2011. **91**(4): p. 773-781.

[62] Vaishnav, D., B.R. Rao, and D. Bade, *Deep Learning Techniques for Object Detection.* Machine learning, 2019. **6**(10).

[63] Redmon, J., et al., *You only look once: Unified, real-time object detection.* in *Proceedings of the IEEE conference on computer vision and pattern recognition.* 2016.

[64] Jakkula, V., *Tutorial on support vector machine (svm).* School of EECS, Washington State University, 2006. **37**.

[65] Simonyan, K. and A. Zisserman, *Very deep convolutional networks for large-scale image recognition.* arXiv preprint arXiv:1409.1556, 2014.

[66] Bearman, A. and C. Dong, *Human pose estimation and activity classification using convolutional neural networks.* CS231n Course Project Reports, 2015.

[67] Hu, C., et al., *Extraction of parametric human model for posture recognition using genetic algorithm.* in *Proceedings Fourth IEEE International Conference on Automatic Face and Gesture Recognition (Cat. No. PR00580).* 2000. IEEE.

[68] Zhang, H., X. Yan, and H. Li, *Ergonomic posture recognition using 3D view-invariant features from single ordinary camera.* Automation in Construction, 2018. **94**: p. 1-10.

[69] Zhang, Z., et al., *A novel method for user-defined human posture recognition using Kinect.* in *2014 7th International Congress on image and signal processing*. 2014. IEEE.

[70] Zhang, S. and V. Callaghan, *Real-time human posture recognition using an adaptive hybrid classifier.* International Journal of Machine Learning and Cybernetics, 2021. **12**(2): p. 489-499.

[71] *What Is Blender (Software)? – Simply Explained*; Available from: https://all3dp.com/2/blender-simply-explained/.

[72] Sabbagh, A.J., et al., *Roadmap for Developing Complex Virtual Reality Simulation Scenarios: Subpial Neurosurgical Tumor Resection Model.* World Neurosurg, 2020. **139**: p. e220-e229.

[73] Guo, C. and J. Pegna, *Review of Circle Measurements in Computer Vision and Novel Use of Computational Geometry in Image Metrology.* in *Computer Graphics International Conference.* 1998. IEEE Computer Society.

[74] *Equation of a circle passing through 3 points*; Available from: http://www.ambrsoft.com/trigocalc/circle3d.htm.

[75] *Oculus Quest*; Available from: https://www.oculus.com/quest/.

[76] Khan, M. and J. Chakareski, *Visible light communication for next generation untethered virtual reality systems.* in *2019 IEEE International Conference on Communications Workshops (ICC Workshops).* 2019. IEEE.

[77] Srivastav, V., et al., *MVOR: A multi-view RGB-D operating room dataset for 2D and 3D human pose estimation.* arXiv preprint arXiv:1808.08180, 2018.

Appendix A

This questionnaire to assess which surgical skills training directors and residents consider important for residents to perform or at least understand by the end of residency training

(1) Gender

- ☐ Male
- ☐ Female

(2) Age

- ☐ 25-35
- ☐ 35-45
- ☐ 45-55
- ☐ >55

(3) What is your educational level?

- ☐ Junior resident
- ☐ Senior resident
- ☐ Specialist
- ☐ Board-certified surgeon (Consultant)

(4) Where do you practice?
Please specify:

- ☐ Country:

- ☐ City:

(5) Type of institution

- ☐ Tertiary hospital
- ☐ Community Hospital
- ☐ University hospital

(6) Do you have residency program in your hospital?

- ☐ Yes
- ☐ No

(7) Do you practice any kind of rehearsal before operations?

- ☐ Yes
- ☐ No
- ☐ Sometimes

(8) What do you usually do in term of rehearsal?

Review medical imaging of the patient (MRI, CT, ultrasound, Xray)	☐ Yes	☐ No
Review the anatomy	☐ Yes	☐ No
Discussion	☐ Yes	☐ No
Mental rehearsal (mental visualization of the surgical steps)	☐ Yes	☐ No
Review of neurosurgical generated images	☐ Yes	☐ No
Other	☐ Yes	☐ No

(9) What is your opinion of the following rehearsal methods?

Review medical imaging of the patient (MRI, CT, ultrasound, Xray)	□ Essential	□ Useful	□ Neutral	□ Not useful	□ Negative impact
Review the anatomy	□ Essential	□ Useful	□ Neutral	□ Not useful	□ Negative impact
Discussion	□ Essential	□ Useful	□ Neutral	□ Not useful	□ Negative impact
Mental rehearsal (mental visualization of the surgical steps)	□ Essential	□ Useful	□ Neutral	□ Not useful	□ Negative impact
Review of neurosurgical generated images	□ Essential	□ Useful	□ Neutral	□ Not useful	□ Negative impact
Other	□ Essential	□ Useful	□ Neutral	□ Not useful	□ Negative impact

(10) Mark the available methods do programs offer for teaching surgical skills your program offers.

- □ Cadaver
- □ Synthetic models
- □ Virtual reality models
- □ Web based learning
- □ Live animals
- □ Scheduled surgical lectures
- □ Training on live surgery
- □ Apprenticeship model (learning by doing)
- □ Other – please specify

(11) List the top 4 skills in your specialty that you consider necessary and essential for a resident to graduate from the program.

1.
2.
3.
4.

(12) Can you suggest a better way of assessing surgical training performance?

- ☐ Cadaver
- ☐ Synthetic models
- ☐ Virtual reality models
- ☐ Web based learning
- ☐ Live animals
- ☐ Scheduled surgical lectures
- ☐ Other – please specify

(13) Have you ever experienced virtual reality surgical simulation in training?

- ☐ Yes
- ☐ No

(14) Do you believe that VR technology can serve surgical training?

- ☐ Yes
- ☐ No

(15) If there is a surgical virtual reality simulation event, would you be interested to participate or attend?

- ☐ Yes
- ☐ No

(16) Give the top five surgical procedures or tasks in your specialty where you would want the VR to fill the gap in training and or rehearsal?

1.
2.
3.
4.
5.

(17) On average, How many surgeries do you perform per month?

(18) What is your specialty?

- ☐ Neurosurgery
- ☐ General surgery
- ☐ Thoracic surgery
- ☐ Vascular surgery
- ☐ Cardiac surgery
- ☐ Plastic surgery
- ☐ Pediatric surgery
- ☐ Ent surgery
- ☐ Orthopedic surgery
- ☐ Ophthalmologic surgery
- ☐ OBGYN
- ☐ Other – please specify
    - If the user clicks other than neurosurgery → end of survey

(19) On average, how many craniotomies are you involved with per month?

(20) For how many years have you been practicing at your current level (resident, specialist, or consultant)?

- ☐ 0-1
- ☐ 1-5
- ☐ 5-10
- ☐ 10-15
- ☐ 15-20
- ☐ >20

(21) What are the two subspecialties you most practice mostly?

- ☐ Pediatric neurosurgery
- ☐ Neuro-oncology
- ☐ Spinal surgery
- ☐ Neurovascular surgery
- ☐ Skull-base surgery

- ☐ Functional neurosurgery
- ☐ Traumatology
- ☐ Other – please specify

(22) Have you explored any of the following virtual reality surgical simulators?

- ☐ Neuro VR (Neuro Touch)
- ☐ Immersive Touch
- ☐ Surgical theater
- ☐ Dextroscope
- ☐ Other – please specify
- ☐ None

(23) What are the operations you would like to see in the virtual reality simulator for rehearsals and trainings?

- ☐ Burr hole selection
- ☐ Endoscopic ventricular landmarks
- ☐ Endoscopic ventricular test
- ☐ Endoscopic nasal navigation
- ☐ Nasal debridement
- ☐ Hemostasis
- ☐ Tumor debulking
- ☐ Tumor resection
- ☐ Fiber exposure and cutting
- ☐ Aneurysm exposure
- ☐ Sphenoid ostium drilling
- ☐ Ethmoidectomy
- ☐ ETV floor perforation
- ☐ Meningioma
- ☐ Glioma
- ☐ Other – please specify

(24) Where do you feel is the gap in the existing neurosurgical training in the Pre-operative phase?

A- OR ergonomics

- ☐ Proper spatial organization and positioning of surgical, nursing and anesthetic teams and their equipment to optimize the ability of the team to visualize team designated fields, screens and equipment and reach required instruments to facilitate optimum procedure performance and decrease musculoskeletal fatigue and injury to the team members.

(25) Where do you feel is the gap in the existing neurosurgical training in the Pre-operative phase?

B- Patient preparation phase:

- ☐ Patient head position (head light, Mayfield)
- ☐ Proper patient body position
- ☐ Neuro-navigation
- ☐ Decide incision (tailoring type and locate of incision)
- ☐ Draping (insuring that the surgical field is properly exposed)

(26) Where do you feel is the gap in the existing neurosurgical training in the Pre-operative phase?

C- Approach:

- ☐ Scalp incision
- ☐ Bone flap removal
- ☐ Dural opening
- ☐ Open and close scalp incisions
- ☐ Perform ventriculostomies, place lumbar drains and intracranial monitors
- ☐ Position patients for craniotomy
- ☐ Perform the opening and closing of craniotomies
- ☐ Resect skull lesions
- ☐ Perform image guided biopsies
- ☐ Demonstrate facility with the use of surgical instruments including operating microscope and endoscope

- ☐ Identify interface between tumor and brain and use as operating plane for tumor resection
- ☐ Identify anatomic landmarks, functional regions, and major structures
- ☐ Show how to minimize and control intraoperative bleeding
- ☐ Perform resection of extra axial and intra axial brain tumors
- ☐ Perform resection of supratentorial and infratentorial brain tumors
- ☐ Perform resection of pituitary lesions
- ☐ Perform basic skull base procedures
- ☐ Detect and handle unexpected complications
- ☐ Drilling burr holes
- ☐ Care of closed head injury
- ☐ Clinical assessment of multi trauma patient
- ☐ Clinical neurological assessment
- ☐ Cranioplasty
- ☐ Craniotomy flaps
- ☐ Drilling bone dissections
- ☐ ICP monitoring
- ☐ Image guidance registration
- ☐ Lumbar puncture
- ☐ Management of potential spinal injury
- ☐ Operating microscope set up and use
- ☐ Post-operative bleed
- ☐ Spinal Operating room positioning
- ☐ Ultrasonic aspirator
- ☐ Ventriculostomy placement
- ☐ VP strut
- ☐ Other – please specify

(27) Where do you feel is the gap in the existing neurosurgical training in the Pre-operative phase?

D- Closure:

E- Lesion resection

(28) How important is the patient positioning technique compared with the other skills?

- ☐ Essential
- ☐ Very important
- ☐ Neutral
- ☐ Not important

خوارزمية التدريب والتقييم لوضعية الجراح في غرفة العمليات باستخدام الواقع الافتراضي والتعلم الآلي

اسم الباحثة

هند هزاع طلال الشريف

بحث مقدم لنيل درجة الدكتوراه في علوم الحاسبات

اشراف

أ.د. وديع صالح الحلبي

د. عبدالرحمن جعفر صباغ

كلية الحاسبات وتقنية المعلومات
جامعة الملك عبد العزيز
جدة – المملكة العربية السعودية

ربيع الأول 1443 هـ – نوفمبر 2021 م

بسم الله الرحمن الرحيم

إهداء

إلى أبي العطوف.... قدوتي، ومثلي الأعلى في الحياة، فهو من دعمني لأتم مراحلي الدراسية.

إلى أمي الحنونة...... لا أجد كلمات يمكن أن تمنحها حقها، فهي ملحمة الحب وفرحة العمر، ومثال التفاني والعطاء.

إلى إخوتي.... سندي وعضدي ومشاطري أفراحي وأحزاني.

إلى زوجي.... رفيق دربي.

إلى أولادي..... فلذات الأكباد.

إلى جميع من شارك وساهم في إتمام هذا البحث لكم كل الود والامتنان

الملخص

يواجه التدريب الجراحي التقليدي العديد من التحديات المتعلقة بسلامة المرضى، وقيود ساعات العمل، وتكلفة غرفة العمليات، وكذلك العديد من المضاعفات الوارد حدوثها. يوفر التدريب الجراحي والتدريب على المهارات فرصة لتعليم وممارسة المهارات المتقدمة خارج بيئة غرفة العمليات وقبل اجراء العمليات على المرضى.

تتميز الجراحة العصبية على وجه الخصوص بإجراءات معقدة تقنيا وتتطلب وقتا طويلا من التدريب. لذلك، تحسين التدريب والتعليم له أهمية لكل من جراحي الأعصاب ومرضاهم.

تظهر محاكاة الواقع الافتراضي كطريقة تدريس قوية يمكن أن تسهل تعلم المهارات وتوفر حلاً محتملاً للتحدي الذي يواجه مديرو البرامج في توفير تدريب هادف في مهارات بيئة العمل المتعلقة بوضعية الجراح المناسبة في غرفة العمليات. وقد أظهرت تطبيقات المحاكاة الافتراضي تحسن في الأداء في غرفة العمليات. ينقسم البحث المنشأ الي دراستين. تهدف الدراسة الأولى إلى تدريب المقيمين على المهارات الأساسية (زاوية العنق وارتفاع الطاولة فيما يتعلق بارتفاع الكوع) التي يحتاجون إليها أثناء إجراء جراحة العمود الفقري. الهدف الرئيسي هو زيادة ممارسات العمل لموظفي الرعاية الصحية بهدف تقليل الإصابات وتحسين الجودة وتجنب الآثار الصحية الضارة المحتملة للعاملين الطبيين (مثل الأطباء والجراحين والممرضات وأطباء التخدير، إلخ). تتمثل الأهداف الرئيسية لهذه الدراسة في تصميم وتنفيذ محاكاة افتراضية منخفضة التكلفة وعالية الجودة. التحدي الرئيسي هو كسر الوقت والتكلفة من خلال تطوير جهاز محاكاة يمكن استخدامه خارج الحرم الجامعي. بعد الانتهاء من تصميم جهاز محاكاة الواقع الافتراضي سوف يتم إدخاله في مرحله التحقق من صحة تطبيقه للأهداف المصمم من اجلها. أظهر النموذج المصمم أن دمج عمليات المحاكاة في تدريب المقيمين، والعمليات الجراحية المحاكاة ستعزز مهارات الجراح ونتائجه.

تهدف الدراسة الثانية الي بناء خوارزميه التعلم باستخدام بعض الخوارزميات مثل(YOLO, HOG, CNN,VGG-16) لتقدير أوضاع الجراحين اثناء العمليات. ستوفر بنا هذه التقنية معلومات حول الجراحين والفريق بما في ذلك الممرضات والمساعدين والمقيمين وغيرهم. ستقدم الخوارزميات تقريرا في النهاية يقيس بدقة المهارات المستهدف قياسها. أظهرت النتائج نسبة أداء جيدة جدا ويمكن التحسين بها باستخدام عدد أكبر من الأمثلة.

الكلمات المفتاحية: محاكاة، تدريب، مهارات، الواقع الافتراضي، تعلم الآلة، خوارزميات