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Master Thesis

Design and Test of an Instrument Carrier for a Collaborative OR Robot

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Abstract

Global epidemics have unforeseen impacts on nursing education and training, making it challenging to maintain a well-trained nursing workforce. To address these obstacles, implementing a Collaborative Operating Room (OR) robot, commonly referred to as a "Cobot," capable of executing predefined instructions and utilizing a conventional gripper to handle instruments, would be highly beneficial. However, it is essential to note that the overall duration of the process of picking tools from the tray and handing them over to the surgeon is longer. This thesis proposes a viable solution to this issue by developing a new instrument carrier system and conducting tests to achieve faster and safer instrument transfers. The experimental setup includes an instrument tray, a Cobot, an instrument carriage system, and a computer device with a microphone for speech recognition. The results of the experiment demonstrate the successful picking and carrying of different instruments by the carrier system, with an average completion time of less than six seconds. Additionally, the thesis explores various factors affecting the duration of surgical instrument transfers, such as the use of a customized instrument tray to eliminate repetitive registration, the application of speech recognition techniques, and the consideration of safety measures. Future research endeavours should prioritize the implementation of computer vision methods for instrument recognition and the development of strategies for retrieving instruments from the surgeon.

Acknowledgement

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List of Acronyms

ISO International Organization for Standardization

PDF Portable Document Format

HRC Human Robot Colloboration

CAD Computer Aided Drafting

STL StereoLithography

STEP Standard for the Exchange of Product Data

IGES Initial Graphics Exchange Specification

PLA Polylactic Acid

PETG Polyethylene Terephthalate Glycol

PC Polycarbonate

Flex Flexible filament

PVB Polyvinyl Butyral

PA Polyamide (Nylon)

CM Centimeter

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1 Introduction

In this Chapter, the thesis work's introduction will be discussed. Starting with the motivation for the thesis work, followed by the aim and structure of the thesis work

1.1 Motivation

Robots and similar technology are increasingly being used in operations to address the scarcity of surgical assistants (nurses). According to the "Dynamic health staff"[1] blog records, Germany will continue to have a severe medical manpower deficit by 2030. Approximately 14,000 nurses and 8,000 intensive care positions were vacant in German clinics. The vacancy rate for nurses in regular wards is about 6%. In comparison, it is about 12% in intensive care units. To overcome the shortage of nurses, we must introduce collaborative robots to perform various routine tasks in hospitals. Considering the fast expansion and development of technology, the use of robotic technology in the medical industry is growing substantially. The DaVinci robot, for example, operates as the surgeon guides it. The robots, on the other hand, may perform a variety of support jobs within the operating room.

Initially, robots are designed to perform tedious, grimy, and menacing tasks. They were engaged in areas of various applications such as assembly lines, painting complex parts, radiation zones as an observer, interplanetary exploration, and complicated surgeries [1]. The new-age robot arm can outperform normal humans by repeatedly lifting heavy weights and cutting labour costs. The robot's grippers replicate a human's hand, which helps pick and place the required objects. These grippers can directly grasp the work-piece or object, likewise the human fingers [2].

Increasingly scientists, engineers, and even medical professionals are becoming interested in robot grippers. Additionally, it can be used as a tool for a wide range of applications, not just as a new and emerging research area. Grippers have different applications, one of which is grasping. The end effector of each manipulator must be fitted with a gripper for learning tasks. When selecting a gripper type, it is essential to consider factors such as manipulation speed, object shape, weight, etc. [3] The shapes and sizes of some grippers may vary with different geometries depending on the application.

[1] https://dynamichealthstaff.com/blog/the-lack-of-nursing-personnel-in-germany-continues-to-worsen/

1.2 Aim of the thesis

In general, the scrub nurse uses their hands to give the surgeon the necessary instruments. A collaborative robot equipped with a gripper can replicate the scrub nurse handing over the tools to the surgeon. However, the whole process is challenging, time-consuming, and sometimes the instruments are mishandled. This entire circumstance has the potential to affect the overall outcome in an operation theatre.

The main goal of this thesis work is to design an instrument carrier system with 3d-printed parts that take less time to transport the instrument from the tray to the surgeon by replacing the collaborative robot's traditional gripper. Additionally, a cost-effective tray and speech recognition module(for taking input commands from the surgeon) will be developed. The entire framework is going to be documented and the research questions which are going to be addressed in this work are,

- How can a simple instrument carrier system and an instrument tray setup with single-usage 3d printed parts be designed?
- How to minimize the duration taken by the conventional gripper to hand over the instrument to less than 6 seconds by ensuring the patient and surgeon's safety?
- How can the collaborative robot take the input commands from the surgeon?

1.3 Structure of the thesis

The structure of this thesis work is discussed below,

1. **Introduction:**1 In the first chapter, the thesis discusses the motivation behind developing an instrument carrier system, outlines the objectives, and provides an overview of the thesis framework.
2. **Background:**2 The second chapter discusses about the background information on robotic grippers, instrument trays, and speech recognition techniques.
3. **Related work:**3 this Chapter explores previous work done in the field of gripper technologies and human-robot collaboration, as well as an examination of existing instrument trays and speech recognition modules.
4. **State of Art:**4 This chapter offers a comprehensive explanation of the concepts behind designing the instrument carrier system and presents the expected outcomes of the thesis work.
5. **Implementation:**5 Chapter five provides a step-by-step procedure for implementing the instrument carrier system, instrument tray, and offline speech recognition model.

6. **Experimental Setup:**6 Starting with the experimental setup of the system, this chapter also discusses the conducted experiments.

7. **Results:**7 This chapter presents the results of the conducted experiments, including material usage and associated costs.

8. **Conclusion and Future work:**8 The final chapter concludes the thesis by summarizing the findings and discussing the potential future developments of research.

2 Background

This chapter provides a comprehensive background on key concepts relevant to the research topic. It covers three main areas: robotic grippers, surgical instrument trays, and speech recognition.

2.1 Robotic grippers

Grippers are essential for robots to securely handle objects. They enhance operations in manufacturing processes, including inspection, assembly, and pick-and-place tasks. Integration with collaborative robot arms improves efficiency and optimization.

2.1.1 Grippers for industry

Mass-production grippers are usually held on stationary platforms. In the beginning, grippers were developed for industrial purposes. Various aspects of industrial grippers can be examined, including geometrical conditions of gripping, position and orientation of gripping, static equilibrium of grasped objects, and dynamic conditions [4]. Specifically, we look for adaptable, flexible grippers that perform well.

Industrial grippers can be categorised based on known and unknown environments. In 1961, General Motors installed the UNIMATE as the first industrial robot [5, 6]. Using this manipulator, die-cast metal pieces were grasped with rigid parallel grips. In the past, these grippers have been powered by electric motors or hydraulic actuators, but in recent years, shape memory alloys and piezoelectric have been used.

Figure 2.1: UNIMATE Robot [1]

2.1.2 Grippers for fragility-prone objects

With advancements in end-effector sensors, the consideration of handling fragile objects has become crucial. A lettuce harvesting end-effector was developed [7], incorporating a machine vision device, six photoelectric sensors, and a fuzzy logic controller. This design achieved a success rate of 94.12%, enabling the harvesting of lettuce at a rate of one lettuce every five seconds.

In a study by Pettersson et al. [8], an insulated hygienic food gripper with force feedback sensors was devised. One finger on the gripper remains fixed, while the other finger moves through magnetic attraction. An inner magnet maintains the actuator's position, while an outer magnet controls the finger's movement along the container's outer surface.

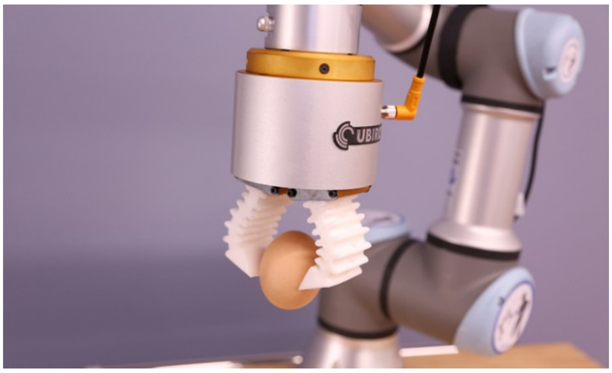


Figure 2.2: Gripper for fragile objects [2]

In QanSun et.al [9], one more fruit-grasping design was evaluated. To minimise unnecessary fruit damage, this end-effector combines both clamping and cutting. A machine vision unit is utilised in a similar model to harvest strawberries [10].

Figure 2.3: Gripper for fruits [3]

[1] `https://lh3.googleusercontent.com/ci/AJFM8rztw9K5pqgupiRsqj3PopqriGeHYauRt_FZN0veqGlPUan9kD7KDWs-2IN9ebtrRowHRxvQhTba=s1200`
[2] https://ubiros.com/images/food-packaging-33.jpg
[3] https://catalog.fa.com.my/image/cache/catalog/SRT/SRT1-500x500.png

For processing sliced fruit and vegetables, an end-effector worked by a Bernoulli principle was developed. It enables the items to be lifted while limiting contact by leveraging airflow over the surface. This minimises the risk of cross-contamination and damage. A further advantage of using this type of gripper is that it decreases the level of moisture on the object's surface. This gripper was created and tested for its suitability in handling food products [11].

Figure 2.4: Processing fruits and vegetables by "*Bernoulliprinciple*" [4]

In [12], a robotic gripper was implemented to evaluate mango solidity and accelerometers equipped in the gripper fingers were utilized to test mango harvest time. The outcomes were linked to the mango ripeness index, and the robotic gripper worked successfully for this task.

A hybrid tomato picking gripper with an effective configuration was also developed [13]. This gripper was able to take out tomatoes with short peduncles, but somehow it struggled when there were leaves and stems in the path.In [14] a related gripper was designed, which has four foam-padded fingers to protect the fruit. The tomato is drawn to the centre when the fingers come together, where a suction cup aids in the grip. It could pick tomatoes at a frequency of 74.6 seconds per fruit and with a 95.35% adhesion success rate. [6]

Figure 2.5: Tomato picker [5]

2.1.3 Grippers for medical applications

Insufficiency of force feedback is one of the big concerns with the use of robotic grippers in surgery. There is also a possibility for serious harm to biological tissues. Microfiber grippers are ideal for use in the medical field due to their inherent safety and self-limiting features, which allow for safe interaction with biological tissues.

[4]https://ars.els-cdn.com/content/image/1-s2.0-S0736584506001347-gr1.jpg

[6]Image source: `https://image.cnbcfm.com/api/v1/image/105907485-1557524937744root6.jpg?v=1557525037&w=1600&h=900`

In [15], for extensive surgery, a soft gripper is created for gentle and secure interaction. This design is equipped with an easily scalable, elastomeric material that can withstand a maximum force of 1 N.

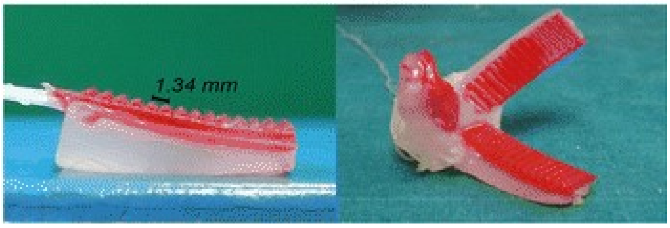


Figure 2.6: Soft Gripper [15]

A viscoelastic force field-controlled robotic gripper was created in [16]. In this task, a two-finger precision grip control layout was developed and analyzed, also it was observed that thumb and finger force are highly correlated. Precision grip control offers adaptability, enabling users to grip objects based on their mechanical properties. Although this design provided insight into the ability to adapt to undisclosed precision grip dynamics, it is constrained to linear 1-D gripping and no outcomes for the performance of gripping of nonrigid objects were reported. Another use for robotic grippers is in robotic surgery. Because of the harmful effects of unforeseen events such as time delay in telesurgery, robotic surgery involves safety and autonomous control.

Based on the tissue excision application [17], a star-shaped micro-gripper was designed and developed. They proved that these developed micro grippers can extract tissue samples from real organs and difficult-to-reach places inside the body by conducting experiments on live animals. These grippers are made with traditional multi-layer micro-fabrication techniques and are actuated by a magnetic field.

A soft robotic gripper has been proposed for use in minimally invasive surgical procedures [15]. The researchers utilized just soft materials and an under-actuated mechanism in their model to adapt the finger shape and apply a certain amount of force. This gripper was developed as a surgical instrument and was composed of soft fabric to allow for secure operations. Furthermore, soft gripper technologies are safe for surgery due to the moderate gripper force.

For retraction procedures in minimally invasive surgery in [18], a small robotic gripper was created. They proved that the gripper had a maximum gripping force of 5.3 N. Its gripper's structure allows it to operate within a small access port. They included brushless motors to provide more degrees of freedom through magnetic anchoring while also enhancing overall platform mobility.

According to [19], surgical forceps with four degrees of freedom and a force sensor are being designed for minimally invasive surgery. For force-feedback control, the dragging and grabbing forces may be monitored. Their concept was proven experimentally on the open-source surgical robot platform Raven-II. 2016 Robotics 5, 11 7 of 20.

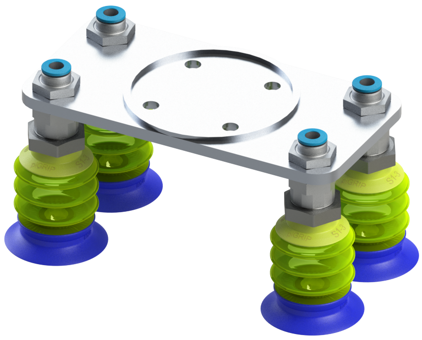


Figure 2.7: Suction gripper [7]

Medical applications can also benefit from suction [20]. Grips of this kind are developed to grasp large, delicate, flexible and slippery body parts, such as the bowel. As a result of this technique, bowel sections can be grasped firmly. However, a manual approach has not yet been tested. An ideal solution would be to use a vacuum pump.

Regarding tissue manipulation mentioned in [21], a soft pneumatic chamber manipulator was developed. This can grasp objects as tiny as 2 mm with a gripping force three times that of forceps grippers, preventing tissue injury during surgical manipulation.

Considering medical purposes in [22], a magnetically guided and operated Mill-gripper was created. It was demonstrated that permanent magnets might be utilized to guide grippers in both tethered and untethered versions. This is an incorporated capsule consisting of an electromagnetic coil, a soft magnetic cobalt iron core, and a magnet.

Surgical grippers have recently become more trustworthy for tasks such as robotic surgery, and minimally invasive surgery. Current advancements include inventing and deploying high-tech actuators, as well as constructing innovative mechanisms. Even though several publications address the force control problem in clinical uses, the barrier of force control endures.

2.1.4 Grippers based on configuration

As highlighted in the findings of [23], a diverse range of grippers can be observed, distinguished by the number of fingers and their respective geometries.

1. **Robot gripper with 2 fingers:**

   They're the most basic robot grippers, ideal for a wide range of industrial items and simple to fabricate. This category has several options, including opening control, pressure control, distance control in both directions and picking up pieces by placing two fingers within a hole. They can also be actuated by pneumatic or electric systems.

[7] https://msitec.com/wp-content/uploads/2020/07/55-0100-001-21.png

Figure 2.8: Gripper with 2 Fingers [23]

2. **Robot grippers with 3 fingers:**

   This sort of robot gripper is rarely utilized because most automation scenarios can be addressed with a two-finger gripper. Three-finger grippers, on the other hand, are ideal for picking up fragile things with force and accuracy. Furthermore, because they have articulated fingers, they fit even better in non-flat areas. Due to the numerous distinct components to pick up, a versatile and adaptive gripper is required. Therefore, the more complexity, the greater the cost of the gripper, which is twice the cost of two-finger grippers. Handling lengthy tubes is one benefit of these grippers since it improves aligning and effectiveness in fast spins. Additionally, there are grippers with tiny non-articulated fingers that are cheaper and can pick up little cylindrical items.

Figure 2.9: Gripper with 3 fingers [8]

3. **Grain-filled flexible ball:**

   This grain-filled latex balloon rests on the thing to be plucked, sucking in the balloon's air and forming a stiff structure that retains the object without hurting

[8] `https://assets.robotiq.com/website-assets/products/header_mobile_image/da430b5116dc87d6ad46e768ffee30f4bc05a432dac3c7c3cb70212beb5976c2.jpg`

it. Because of its simplicity, premise, and adaptability, it received a lot of attention once it was introduced. Following then, there have been changes based on the item to be selected. Modifications include balloon diameter and filling: ground coffee, rice, coffee beans, and so on.

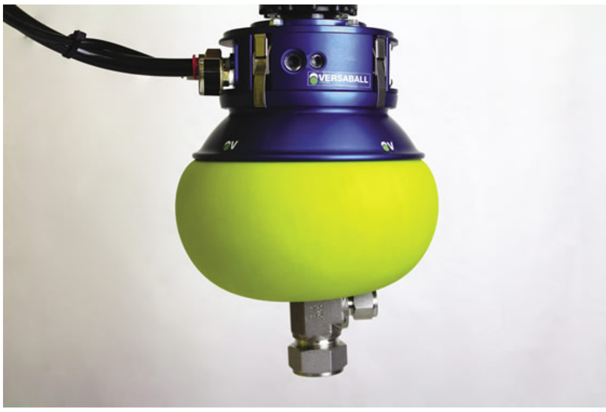


Figure 2.10: Grain-filled flexible ball [9]

2.1.5 Classification-based robotic grippers

Classification-based robotic grippers have gained popularity in recent years because of their ability to recognize items based on physical criteria such as form, size, and texture. Tactile-based robotic grippers and vision-based robotic grippers are the two primary kinds of classification-based robotic grippers. Tactile grippers employ touch sensors to collect information about the item's surface, whereas vision grippers use cameras to collect pictures of the object. Both strategies have pros and cons.

1. **Tactile-based grippers:**

   Tactile-based grippers can enable precise and dependable item recognition by sensing physical attributes like form, texture, and hardness of the object. Numerous scholars have proposed several ways of tactile sensing for item detection. In [24], created a tactile-based robotic gripper that classified items based on their surface qualities using a deformable sensor array. In categorizing items of various forms and sizes, the system reached a precision of 95%.

[9]https://www.ctemag.com/sites/www.ctemag.com/files/article_images/MetalTConnector_opt.jpeg

[10]https://www.iff.fraunhofer.de/en/business-units/robotic-systems/tactile-sensor-systems-gripper/jcr:content/stage/stageParsys/stage_slide/image.img.4col.large.jpg/1463050337375/rs-taktiler-greifer-fraunhofer-iff-b.jpg

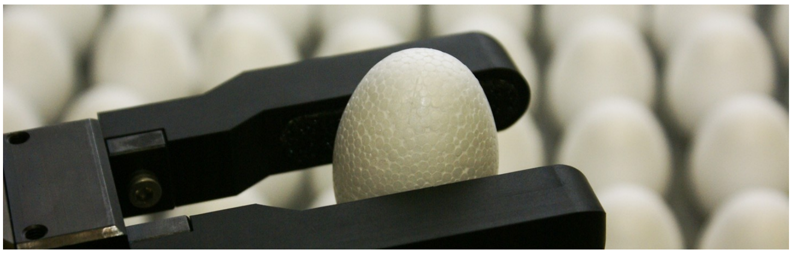


Figure 2.11: Tactile Gripper [10]

2. **Vision-based grippers:**

   Cameras are incorporated into vision-based grippers to take photos of the objects and gather information such as colour, shape, and texture for object recognition. Since vision-based systems may identify things based on a broader variety of physical attributes, they can be more adaptable than tactile-based systems. As [25] suggested a vision-based robotic gripper that classified items based on their shape, texture, and colour using a convolution neural network (CNN). In categorizing items of various forms and sizes, the system obtained an accuracy of 98%.

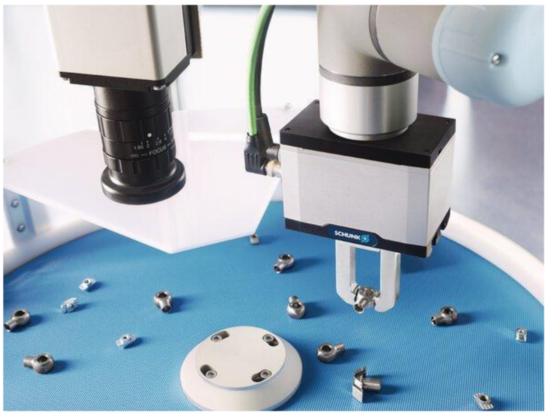


Figure 2.12: Vision-based gripper [11]

3. **Hybrid grippers:**

   To achieve more precise and dependable item detection, hybrid grippers integrate tactile and vision-based sensing approaches. For example, [26] suggested a hybrid gripper that classified items based on their physical attributes using a mix of tactile and vision-based sensing. In recognizing items of various forms and sizes, the system obtained 99% accuracy.

[11] `https://d16vz4puxlsxm1.cloudfront.net/image/076200133045-Prod/image_m36h5f1j0t1j5d403b0chfo17f/-FJPG-S600x450`

[12] `https://www.fluidpowerworld.com/wp-content/uploads/2021/04/csm_GPP5016IL_GPD5016IL_blau_CMYK_026840996a-300x169.jpg`

Figure 2.13: Hybrid Gripper [12]

2.2 Surgical instrument trays

Surgical trays are essential tools used during surgeries to hold and organize surgical instruments and supplies. They are usually made of stainless steel, which is non-reactive and easy to sterilize. The trays come in different sizes and configurations depending on the surgical procedure being performed.

Surgical trays are designed to prevent contamination of surgical instruments and supplies during a surgical procedure. They also help to organize the instruments and supplies so that they are easily accessible to the surgical team.

Figure 2.14: Surgical Instrument Tray [13]

One study by [27] found that the use of surgical trays reduced the risk of infection during surgery. The study showed that the use of surgical trays reduced the number of contaminated instruments and reduced the risk of surgical site infections.

Another study by [28] found that the use of surgical trays improved the efficiency of surgical procedures. The study showed that the use of surgical trays reduced the time taken to locate and retrieve surgical instruments and supplies.

[13]https://ars.els-cdn.com/content/image/1-s2.0-S0022480418302014-gr1.jpg

In general, surgical trays are essential tools in surgical procedures. They help to organize surgical instruments and supplies, reduce the risk of contamination, and improve the efficiency of surgical procedures.

2.3 Speech recognition

Speech is the most natural way for people to interact and word recognition is one of the most fascinating signal processing study topics [29]. Voice recognition technologies in native dialects will allow illiterate/semi-literate individuals to use technology to a larger level without knowing how to use a computer keyboard or a cursor. o ver three decades, much study has been conducted on various areas of voice recognition and its applications. Several devices have been created that successfully use automated voice recognition for human-machine communication.

Transcription is the study of voice signals and their processing techniques. Because the signals are often treated in digital form, speech processing may be thought of as a subset of digital signal processing techniques adapted to audio signals. It is a distinct subject that spans a wide range of technology and purposes.

Automatic speech recognition(ASR) uses tend to be beneficial in people's daily lives [30]. Speech Programming, Text-to-Speech Synthesis, Speech Recognition, Speaker Recognition and Validation, Recommended Methods, Speech Feature extraction and Transcription, Language Identification, Prosody, Attitude and Emotion Recognition, Analogue Signal Encoding, and Dialect Conversation Systems are some of the voice recognition implementations.

2.3.1 Characteristics of speech recognition systems

According to Jacob et.al [31], many aspects influence the design of the automatic speech recognition system. Precisely, modelling units which include words, syllables, and phonemes are utilized for recognition. With vocabulary sizes such as small, medium, and big. Task syntax such as basic to complicated tasks employing N-gram language models and task perplexity. Speech conveying modes such as solitary, linked, uninterrupted and natural. Also includes trained, adaptive, independent or dependent speakers, speaking environments such as quiet rooms and noisy areas, transmitters such as high-quality microphones, telephones, smartphones, array microphones, and communication systems.

2.3.2 Applications of speech recognition

Automatic speech recognition technologies [32], have progressed to the point where increasingly difficult applications are becoming simpler. Voice search and interactions with mobile devices (e.g., Siri on iPhone, Bing's voice search on Windows Phone, and Google Now on Android), smart speakers in home entertainment systems (e.g., Kinect on Xbox), and various speech-centric information processing techniques that benefit from downstream processing of ASR outputs are examples. Text-to-speech systems, voice user interactions, audio dialling, call forwarding, domestic appliance management, command and control, speech-assisted search, easy data entry, hands and eyes-free technologies, and neural nets for handicapped individuals are examples of common uses.

3 Related Work

This chapter explores various aspects related to human-robot collaboration, design configurations for robotic grippers, surgical instrument trays, and the application of speech recognition in surgical robotics.

3.1 Cobot and Human-robot collaboration(HRC)

Collaborative robots are a new form of robot (or cobots). There are robots that can operate alongside humans, doing not just sequential but also parallel activities. Cobots have the following characteristics: The capacity to interact securely with humans, the reduction of risks in implementation activities, flexibility and learning, and the option to be used widely and quickly change. The use of collaborative robotics in manufacturing allows workers and robots to progress beyond cooperation to collaboration, [33, 34].

Development of manufacturing robots has progressed much more than a distinct work environment and are now collaborating with humans, Simply called human-robot collaboration (or HRC). HRC is the most forward-thinking technology in today's Industry 4.0. This is because robots are simple to train and install in the workplace. Collaboration robots feature sophisticated applications which enable machine-learning approaches to be used. Various sensors aboard the cobot and software enable self-learning through technological vision and voice, in addition to motions. With the advancement of technology, HRC now has a vast potential for contemporary enterprises of all sizes and economic sectors. When compared to typical industrial robots, collaborative robots can attract greater investment.

The core issue in modern industries is to maintain the safety and efficiency of human-robot interaction in a volatile and unpredictable environment. On the one hand, numerous cobots in Industry 4.0 are already available from firms such as FANUC, KUKA, Universal Robots, and Rethink Robotics 35 Nowadays, these robots are focused on ISO technological specifications. On the contrary end, we must focus on intellectual and interactive safety during the interaction, as well as acquire relevant data, build cognitive abilities, and recommend strategies. Historically, robotics was divided into two categories: industrial and service. As stated by the experts, [36]. The classification of robotics shown in figure 3.1 represents the current categorization, in which portable and readily adaptive robots now become part of humans both in production and in daily lives.

Furthermore, the use of robots sometimes doesn't necessarily represent the categorization, because the use of a certain type of robot is dependent on the activity being addressed and the competencies of the robot itself.

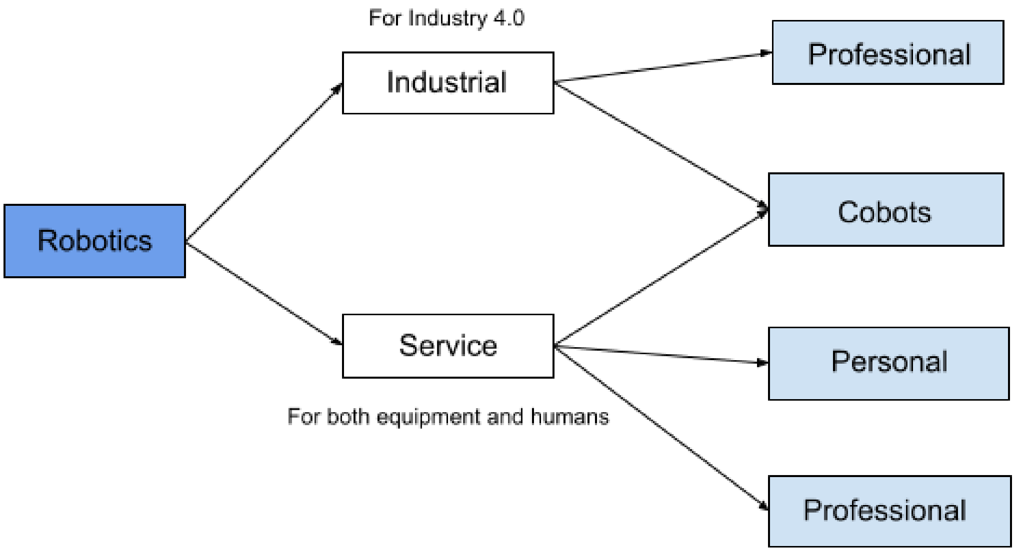


Figure 3.1: Classification of robotics

3.1.1 Effective factory output using human-robot interaction

Human-robot interaction (HRI) in a collaborative workplace might be divided into two scenarios: first, execute distinct activities in a large facility, and second, accomplish each job jointly in a period. This collaboration in sophisticated industrial output may be modelled as a multi-agent robotic system. In the paradigm, there are two basic agents: workers collaborating with each other and cobots operating in human-involved environment.ISO guidelines address HRI safety problems. The standards' goal is to improve the compatibility of cobots and their subsystems. It helps minimize development and maintenance costs by standardizing processes, interfaces, and characteristics [37].

Factor	**Description**
The credibility of the robots	Robots' inability to confidentiality, as well as their views about them, lead to their limited utilization
Workload	A poorly designed work environment with robots adds to manual input
Lack of situation awareness	Inadequate knowledge of the circumstance causes a variety of human mishaps and injuries
Skill degradation	This element demonstrates how automation impacts the outcome of HRI and diminishes the safety protocols of their collaboration
Stress, anxiety and safety due to HRC	This will have an impact on the expression of consequences including stress, anxiety, and safety concern

Table 3.1: Human factors influencing HRC [37]

Human factors create challenges to foreseeing or identifying genuine common human behaviour in HRI. We need empirical data that reveal relevant data to investigate the primary human aspects. This will allow us to compile a basic list of elements influencing HRC. Several scientists' study has yielded the following results in table 3.1 [38–41]

The research into the human aspects of the process of interaction between a human and a robot will provide knowledge of what steps must be done to maintain workplace safety and productivity. The authors of the study's subsequent phase will require a lot of research on real-world instances. Studies will be carried out to evaluate information about human factors and to propose ways to enhance HRI.

3.1.2 Strategies for collaborative robot safety during Human-robot-collaboration

Collaboration instances include a robot and a person in the field of rehabilitation, a human and a driverless car on the road, a toddler and a robot during research, a controller and a controller, as well as a human worker on a robotic lane in manufacturing. According to Haddadin et.al [42], there are two different approaches to ensuring safe interactions between robots and humans. The initial strategy is to change the robot's configuration such that it does not cause injury when it comes into contact with a human (hardware design). Furthermore, according to safety regulations and software design, create a collaborative robot (interactive safety), stated by TSai CS et.al [43]. For a basic understanding, we will emphasise the fundamental HRC approaches governed by guidelines: controllable robot pause, robot controller utilising human movement, framework speed and separation supervision, and restricting the robot's power and force as mentioned by Galin R et.al [44]. As Liu C et.al stated [45], In a multi-agent system, every component is classified as a robot, a robot agent or a human agent. The system agents' purpose is to carry out the task efficiently. Hence, strategies for accomplishing tasks in game theory with active agents whose actions are mutually determined by each others are recommended for safe and successful interactions between an individual and a robot. The cobot should always be intellectual enough to engage in social behaviour while interacting with people in a reliable and secure way, including in cases of emergency. There are three main factors that contribute to this are stated below by Anandan T et.al [46]

- Enhancing robot economic effectiveness when compared to human workers
- The incorporation of these kinds of technical benefits in robotics technologies will enable the effective utilisation of robots in manufacturing markets and the economy.
- The explosive growth of the robotics market

To prevent accidents and injuries when working collectively, the HRC has mainly separated into four protective concepts, that can be referenced in both ISO 10218 and ISO TS 15066 et.al [35, 47]:

- **Dead stop:** The Cobot pauses its activity as long as the worker occupies the common work area.

- **Hand guidance:** The operator can steer the cobot to its destinations physically.
- **Monitoring limitations:** designed or additional sensors restrict impact and the cobot stops if it fails to maintain the specified ranges.
- **Limiting power and force:** Restricting contact forces to a safe limit.

3.2 Design configurations for robotic grippers

To gain insight into the development of grasping devices, it is important to first examine how humans interact with, grasp, and manipulate objects in their everyday activities. In order to achieve this, the Max Planck Institute for Intelligent Systems conducted a research study by Taheri et al. [48] which aimed to enable computers to understand, simulate, and replicate human grasping.

The research conducted involved a comprehensive assessment of various aspects, including complex 3D object shapes, precise contact information, hand posture and shape, and 3D body movements [48]. Similar studies by Cini et al. [49] and Feix et al. [50] categorized different types of grips based on the characteristics of the objects, such as their dimensions and sizes. Figure 3.3 illustrates several gripping types presented by Prakash et al. [51].

In summary, the grasping methods have additional variations depending on the geometry of the objects (as shown in figure 3.2). These variations are categorized as parallel or flat grasping mode, cylindrical grasping mode, and spherical grasping mode [52]. Each of these main categories further includes subgroups, such as Tip mode, Hooke mode, and Lateral mode. Lateral mode, for instance, falls under the parallel mode and is applicable when the object's thickness is much smaller than its perpendicular area. The architecture of robotic grippers can be broadly classified into three categories based on their mobility: fully constrained, under-constrained, and deformable.

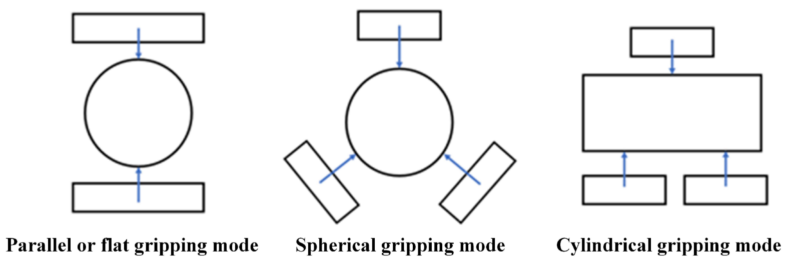


Figure 3.2: Grasping modes for different shaped objects [53]

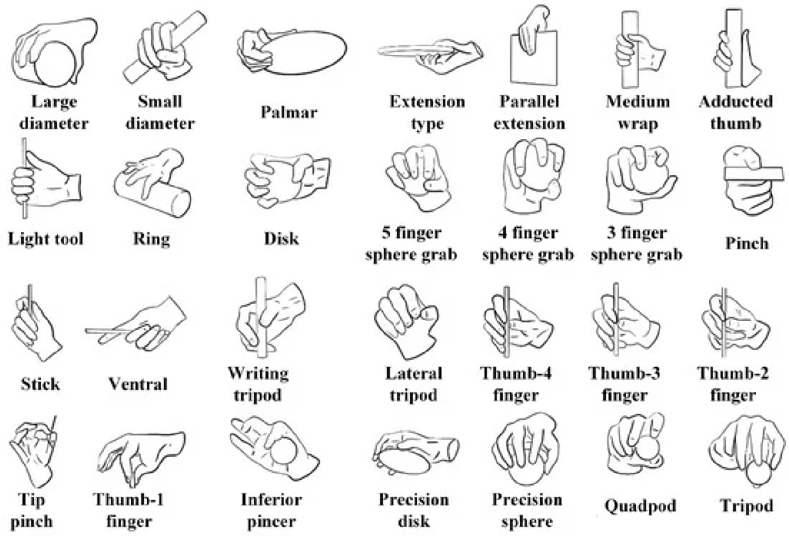


Figure 3.3: Various forms of grasping an object [53]

3.3 Surgical instruments trays

Definition: [1] Based on an architectural standpoint, surgical trays might appear to be flat open or closed boxes. They are an excellent solution for safeguarding and keeping various surgical instruments. Surgical trays are a prevalent feature in most hospitals. As a result, they are employed in hospitals, clinics, research facilities, labs, and particular emergency rooms. A basic surgical instrument tray is made of steel; the grade of the steel frequently dictates the tray's quality. Enamel, aluminium, and polymers are also employed in the production of surgical trays.

Function:[2] Surgical trays are used in a wide range of medical facilities for sterilization, autoclaving, storage, and other therapeutic applications. They are available with or without coverings and have large corners. These broad edges make cleaning, stacking, and handling surgical trays easier. Surgical trays are sometimes called as mayo stands, specialized procedure trays, or operational instruments trays.

3.3.1 Types of surgical trays

Perforated trays, mesh trays, and drying trays are among the three major types of surgical trays as shown in figure 3.4. In the next stage of the conversation, we'll go through them extensively.

[1] Text:https://www.medwish.com/blog/buying-guide/how-to-choose-the-best-surgical-trays-for-operating-room/
[2] 1
[3] Fig:(A,B)https://www.keysurgical.com/products/sterile-processing/packaging-and-preparation/perforated-mayo-trays

Figure 3.4: Types of surgical trays [3]

1. **Perforated tray:[4]**
   PMMA resins, a kind of polymer, are used to make perforated trays. The thermoplastic fabric and a visible moderate curing resin were also employed in the production of the perforated trays. The intensity varies from 25 to 150 mm. The thickness ranges from 1.00 mm to 3.00 mm. Mild steel is utilized in perforated trays.

2. **Mesh tray:[5]**
   Regardless of their unobstructed airflow, wire mesh trays are ideal for sterilizing medical instruments and equipment. Chrome steel 202, 304, and 316 are common materials used in wire mesh trays. The mesh trays, which are electro-galvanized and powder coated, are a great choice for many healthcare establishments. Their thickness ranges between 3 and 10 mm. The heated dip is galvanized, and then fabrication takes place. A mesh tray may be found beside bedside tables or mattresses in healthcare institutions. These trays are frequently used to organize a person's meals, medications, and other items.

3. **Drying tray:[6]**
   Drying trays make things considerably simpler for healthcare professionals by enabling them to gather all of the required surgical instruments in one place. Steam stress is set at 3 kg/cm2, steam input is set at 25 lb/hr, and insulation is set at 50 mm at 100 degrees Celsius. Surgical instruments such as forceps, scissors, blades, cotton, and spirit can be organized and placed on drying trays.

[4] 1

[5] Text:https://www.medwish.com/blog/buying-guide/how-to-choose-the-best-surgical-trays-for-operating-room/

[6] 5

3.3.2 Pros and Cons associated with surgical trays

- **Pros:** [54]
  In fact, there is no competition around surgical trays in terms of strength and rigidity. Steel alloys and composites certainly raise the values to some extent. It is critical to register these benefits without incurring extra pounds. A heavy-weight tray, you know, will ruin the whole purpose of utilizing surgical trays. It all comes down to making things simple! Additionally, future developments in plastic and polymer-based surgical trays represent significant advancements. They can withstand high heat and radiation, making them ideal for use in a variety of clinical situations. To summarize the benefits of surgical trays, terms such as adaptability, dependability, and enhanced protection would be adequate.

- **Cons:** [55]
  Surgical trays may forfeit their stiffness and sturdiness gradually. As a result, if one's objective is to utilize surgical trays for an extended length of time, one needs to anticipate investing an adequate sum of funds over an extended period of time. In addition, surgical trays must be cleaned and sterilized on frequently. If they fail to be sterilized on a regular basis, they may turn into a major source of contamination. As a result, while utilizing surgical trays in a healthcare institution, considerable caution is required.

3.3.3 Importance of customized surgical trays [56]

Some of the foremost prominent advantages of customized surgical trays are that they may save you plenty of time. They may decrease operation time by up to 40%. Medical staff do not have to spend hours arranging their supplies and equipment because all of them are nicely arranged on a tray. Personalised surgical trays can be extremely helpful in emergencies. This subsequently results in better comprehensive service quality. Another significant advantage of customized surgical trays is that they significantly limit the possibility of cross-contamination. It is an enormous convenience for surgeons to get all of the supplies and medical instruments they require combined in a single sterilized box. Custom surgical trays are therefore critical if the goal is to simplify the whole procedure.

3.3.4 Components to be included with a surgical tray [57]

In accordance with the kind of operation, the components of a surgical tray may differ. Some characteristics of a surgical tray, still are shared by all customized surgical trays. Dressings, bowls, sutures, disposable syringes, surgical blades, scalp vein-type needles, forceps, stitch cutters, surgical drapes, personal protection supplies, and towels are among the standard features. It is up to the medical organization to install extra surgical tray components. The kind of procedure that must be carried out affects the selection. Skin surgical trays, for instance, may include a surgical skin staple. Likewise, surgical procedures for handling coronary artery disease may involve the use of a coronary catheter. Nasal oxygen catheters and litigation clips are two other examples. Some unique surgical trays have been launched into retailers based on the requirements of typical surgeries. Angiography, biopsy, interventional radiology drape, pacemaker, and PICC trays are a few instances of these kinds of trays.

3.3.5 Some of the popular and cost-effective surgical trays

Take ourselves to have a look at the costs for some of the most significant surgical trays on the market as discussed in the following table 3.2.

Name of the tray	Description
Stainless steel tray stand trolley with one Post AG-SS008	• Size: 660*400*940/1400mm • 304 stainless steel frame • Height adjustable by screws • Four silent wheels with cross brakes • Price: USD 137.75
TZHW-001 Stainless steel tray	• Available in a variety of sizes • Price: USD 7.11/set
SDXH-015 Stainless steel instrument tray	• Material:304 stainless steel • Model Size:31*24*3.1cm • Price: USD 23.75 per set
Instrument tray CF-12	• Material:304 stainless steel • Model Size: S, M, L

Table 3.2: Properties of Popular Surgical Trays [7]

[7] https://www.medwish.com/blog/buying-guide/how-to-choose-the-best-surgical-trays-for-operating-room/

The surgical procedures are frequently vulnerable, requiring an environment that permits the surgeon and his team to accomplish the surgery appropriately. Without a doubt, everything in the operation room must be organized and put together. Nowadays medical procedures are becoming more complex. Every operating room must have a cutting-edge surgical tray.

As a result, an operation theatre must have the most effective surgical trays, which should include the typical components specified earlier in this summary, in addition to a good and highly qualified medical staff. All of these instruments are useful in the supervision of patient vitals during surgery and the creation of an effective surgical environment.

3.4 Speech recognition for a surgical robot

Speech recognition is widely used in electronic products and personal amenities, but its adoption in industrial and medical applications is typical due to motion uncertainty. This uncertainty occurs with minimally invasive surgical robotic helpers because the robotic motion is not calibrated to the camera views. Considering the adoption of minimally invasive surgery (MIS), contemporary surgical procedures have witnessed major improvements. From the patient's perspective, MIS often leads to a faster recovery rate, fewer scars, fewer soft tissue damage, fewer side effects and fewer days in the hospital. However, due to the specialized nature of the technique, MIS involves hours of additional specialized training for doctors.

In addition to the introduction of powerful computer devices, techniques for natural voice recognition have rapidly evolved. Much research reveals effective applications of speech control for mobile robots [58], humanoid robots [59], and aerial robots [60]. Clients (mobile and personal computer (PC) apps) and scientific researchers have adopted speech control, but commercial applications remain limited. Recently, industrial robots have been outfitted with a human-to-machine interaction method, enabling human-robot collaboration to improve manpower usage.

The combined effort of spoken instruction with robot-assisted MIS commenced with the implementation of the AESOP robot mentioned in Nathan et.al [61] by computerized movements, which was authorized by the FDA in 1994. A laparoscopic camera is attached to the robotic arm near the surgical table on the AESOP robot. A joystick or spoken instructions are used to operate the robotic arm. The key shortcomings of this technology at that time were the latency of the voice recognition engine and the poor recognition rates.

J.Kim et.al stated that One more minuscule surgery assistant featuring a seven-command voice control system and instrument tracking is known as the KaLAR [62]. Unlike AESOP, KaLAR is attached directly to the operating tables. Berkelman et al. presented the LER [63], a light endoscopic robot, in 2003, which led to the development of the ViKY

Uterine Positioner [64]. This robot is placed on the patient's abdomen. The keywords accompanied by instructions activate the ViKY voice-control system. In a comparison study by A.A.Gumbs et.al [65], the ViKY voice recognition system performed 71% better than the AESOP system, which performed 67% better. Although ViKY is the most recent commercially available MIS assistance that employs voice control as the major command input for endoscope placement, there is still space for advancement in surgical speech control. The advantages of voice control in MIS applications with respect to camera holder

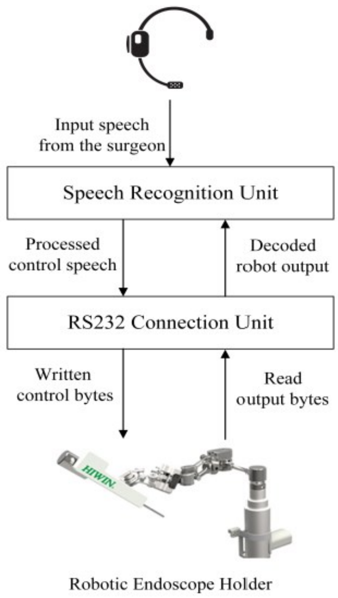


Figure 3.5: A robotic endoscopic system [66]

handling are critical for the creation of a medical-robot interface because it allows robots to be incorporated into surgical teams. To resolve the calibration of voice orders for a range of robotic mobility to that of an object of interest in an endoscopic picture, any ambiguity in the robotic holder's reaction in response to spoken words must be addressed. A feasible system needs to be adept at comprehending speech in real-time. This work offers a concept for an ISR interface to manage a 3-DOF HIWIN robotic endoscope holder during MIS, utilizing serial-port connection for PC to robot command transmission.
The issues that voice control devices encounter across industries are comparable to the ones that arise in medicine. Perrakis et al. examined two current integrated operation systems designed to provide centralized control of all the operating theatre components: the Siemens integrated OR system and the Karl Storz OR1 [67]. One of the most typical systemic issues that annoy surgeons is command misinterpretation. In the context of controller architecture, a single spoken command can correlate to a 5 mm or 5 cm movement. In the lack of versatility in the length of any move, navigation becomes inconsistent and non-intuitive. If the camera is moved to a different location, the commands must be repeated.

4 Conceptual Design

This chapter discusses the main scope of this thesis work, starting from the overall process flow of this work followed by the design of the conventional gripper used earlier to pick the instruments and their drawbacks and how we can overcome those with the proposed designs and the factors influencing it.

4.1 Overall process flowchart of this thesis work

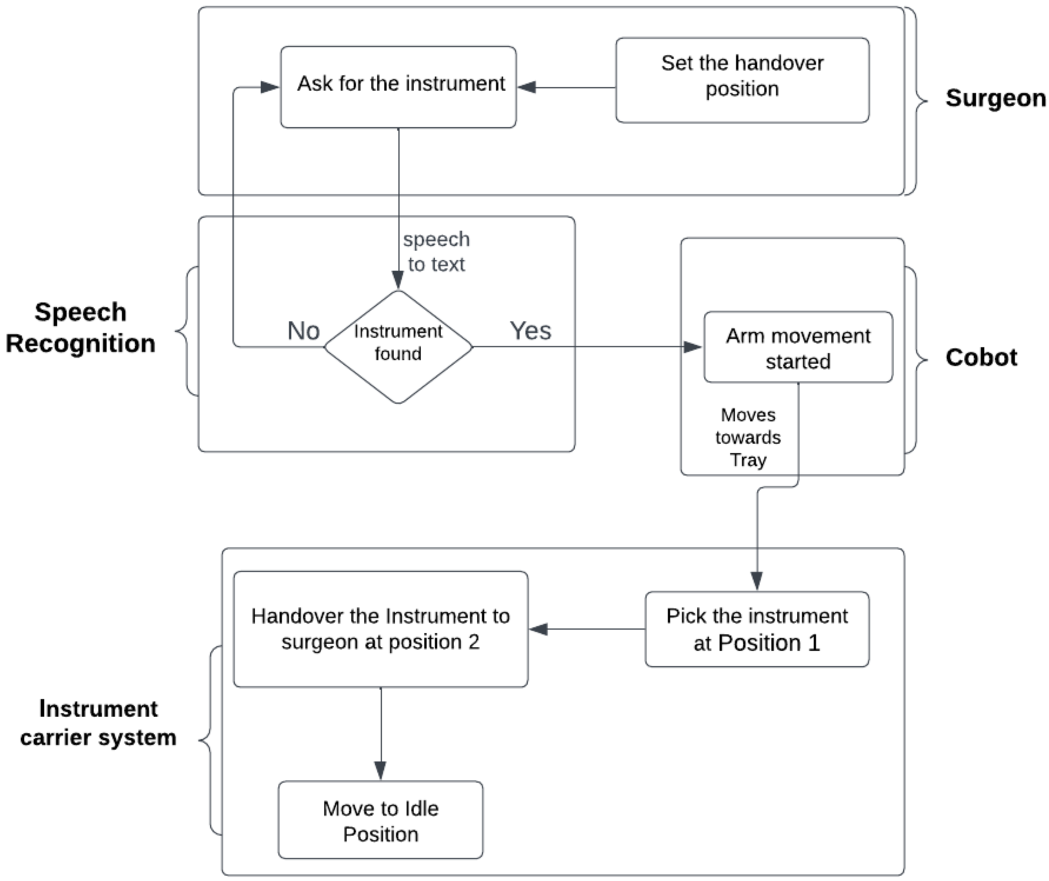


Figure 4.1: Overall Process Flowchart of this thesis work

The overall process flowchart of this thesis work consists of the integration of four separate tasks into a single pipeline.

1. **Surgeon:** The surgeon initially set the cobot's handover position to take the instrument and ask for the required instrument.

2. **Speech recognition:** The setup microphone recognises the instrument name and the speech recognition module converts it to text. If the instrument is found, it will move to the next step or it will again request the instrument.

3. **Cobot:** The Cobot here is Frank-Emika Panda Robot, which is fitted with an instrument carrier system (that going to be designed at the end of this work) and will move towards the instruments tray to the pre-described position of the requested instrument from the surgeon.

4. **Instrument carrier system:** The carrier will pick the instrument from one end (position1) and carry it to the other (position2), which is the pre-set handover position by the surgeon. After the instrument is removed, the carrier and the robot will move to their respected idle position.

The detailed methodology of the designs will be discussed in the following sections

4.2 End effector of a franka-emika panda robot

franka emika's panda Robot is a collaborative robot that has been utilized to handle instruments. A controller equipped with an Ethernet connection allows interaction between the PC and the arm via the Local Area Network (LAN). The Gripper is an electrical two-finger parallel gripper designed for the franka emika robot as shown in the below figure 4.2

Figure 4.2: End effector of a franka-emika panda robot [1]

4.2.1 Drawbacks

While using this end effector to grasp the instruments, many setbacks have arisen some of which are discussed below.

[1]https://raw.githubusercontent.com/cyberbotics/webots/master/docs/guide/images/robots/panda/

- The gripping force of this end effector is not stable, because of this the gripper sometimes displaced the instruments from its designated slots.
- Holding the instruments is inaccurate irrespective of their size and shape.
- This end effector takes much longer to grip and carry the instrument to a predefined handover position. 10-12 seconds.
- Operators safety is also in-stake because there is no protection around the end effector while carrying the instrument.

4.3 List of requirements

Instead of relying on the traditional gripper, a new design of an instrument carrier system is being developed to overcome the drawback of time-consuming instrument handover. This innovative system not only ensures the operator's safety but also enables a faster transition of instruments from the tray to the surgeon. The proposed scrub nurse robot is composed of three segments: Instrument carrier, Robot control, and Tray layout, all working together to perform the functions of a scrub nurse. Additionally, various other requirements are currently being addressed in the ongoing development process.

- The distance between the instrument tray and the handover position should be approximately 1 metre.
- The maximum length and width of the instrument in our list is 24 cm X 7.5 cm, so the carrier should be around (8-12 cm x 8 cm) to transfer it without collisions with safety walls.
- The robot's payload is up to 3kg, so our carrier system including the instrument weight(Maximum=65 grams) should be less than or equal to 2.5kg (for safety).
- The conventional gripper takes around 12 seconds to hand over the instrument, our system should consume less time.
- The instrument tray should be fixed so that the tray registration process can be eliminated.

4.4 Proposed solution

4.4.1 Instrument carrier system

The purpose of an instrument carrier is to make it easy to pick up and transfer the instrument to the surgeon. To ensure sterility in the operating room, we intend to use low-cost 3D-printed parts that may be used and discarded. We will Design using CAD files, then print the required parts using a 3D printer and assemble them according to the working design. The proposed system designs which are going to be discussed in detail as follows

1. **Concept-1:** Closed conveyor system on rollers with fixed platform
2. **Concept-2:** Movable carrier system attached with a platform
3. **Concept-3:** Movable instrument carrier system on a stationary platform

Concept 1:

Closed conveyor system on rollers with fixed platform
The working principle of this system is shown below

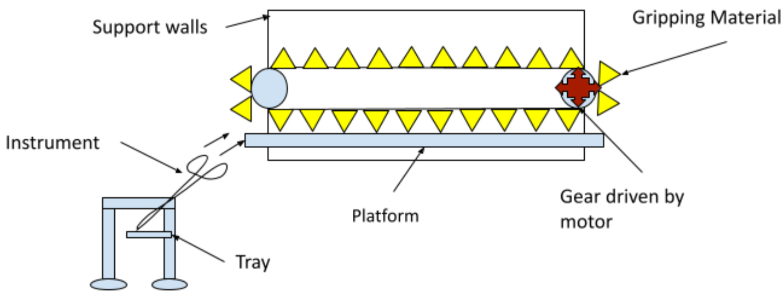


Figure 4.3: Closed conveyor system

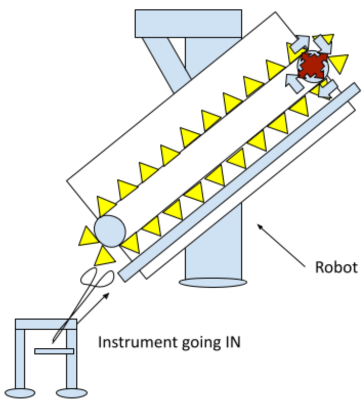


Figure 4.4: Instrument IN

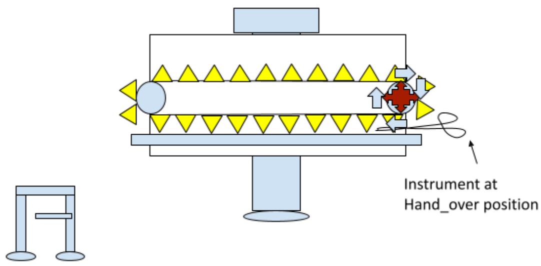


Figure 4.5: Instrument OUT

The closed conveyor system in figure 4.3 comprises a gripping material mounted on motor-driven rollers with gears. This system is securely affixed to a stationary platform and enclosed by supporting walls. Adjacent to this setup, an instrument tray has been positioned. The entire system is integrated into a robotic arm, as illustrated in figure 4.4. The motor-driven rollers with the gripping material are capable of smoothly rolling the instrument inward and transporting it to the handover position, as depicted in figure 4.5

Concept 2: Movable carrier system attached with a platform

The working principle of this system is shown below

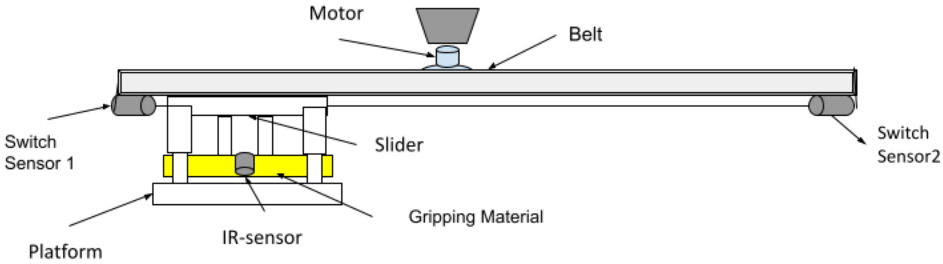


Figure 4.6: Movable carrier system attached with a platform

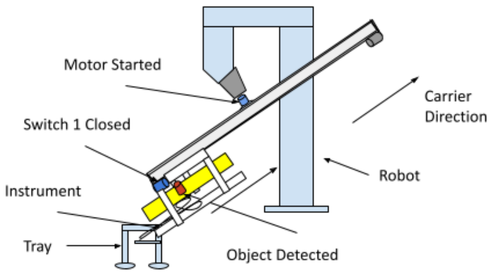


Figure 4.7: Taking Instrument IN

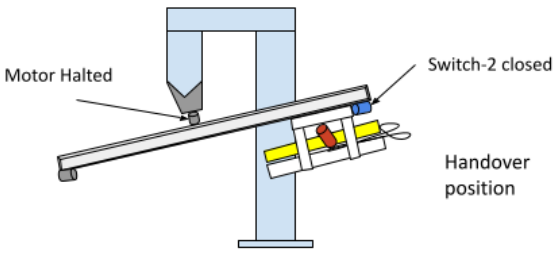


Figure 4.8: Instrument OUT at handover

The movable carrier system, as illustrated in figure 4.6, consists of a long linear guide rail with a belt drive within the rail and a motor attached in the centre to drive it. The belt ends are fastened to a carrier slider that has gripping material on it which was fixed with a platform. It also has two switches and an infrared sensor attached at the top of the grasping material, as shown. This complete system is mounted to a robotic arm, as illustrated in figure 4.7, where the switch sensor 1 closes the carrier and the robotic arm is tilted to an inclined angle to transport the carrier setup to the instrument tray, which is located adjacent to the robot. where the carrier is closed by the switch sensor 1 and the robotic arm is tilted to an inclined angle to take the carrier setup towards the instrument tray which is placed next to the robot. The force created by this angle makes the instrument move in between the gripping material and the platform. Once the instrument is detected by the Infrared sensor and switch 1 is closed the motor starts rotating and transmits it through a belt drive which drives the carrier towards another end until switch 2 is closed and the motor halted as shown in figure 4.8. The motor halts till the instrument is taken out by the surgeon.

Concept 3: Movable instrument carrier system on a stationary platform

The working principle of this system is shown below

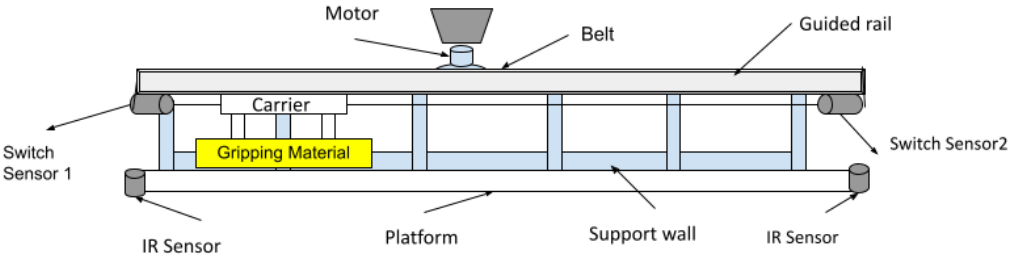


Figure 4.9: Movable instrument carrier system on a stationary platform

The movable carrier system on a stationary platform, as illustrated in figure 4.9, consists of a long linear guide rail with a belt drive within the rail and a motor attached in the centre to drive it. The belt ends are fastened to a carrier that has gripping material on it. This complete arrangement is positioned on a fixed platform that is supported by walls connected to the sides of the guided rail. It also has two switches and two infrared sensors attached to the endpoints of the guided route and platform, as shown.

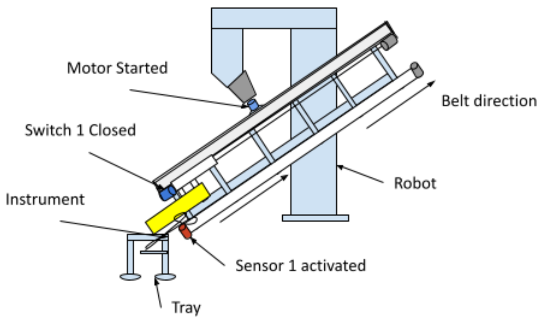


Figure 4.10: Instrument IN carrier

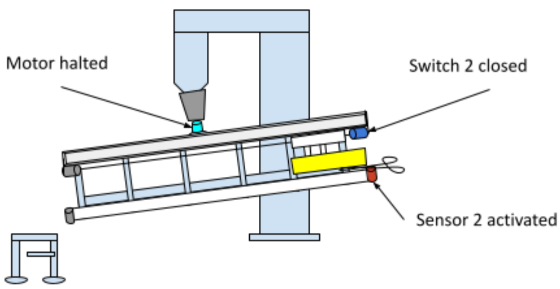


Figure 4.11: Instrument OUT at carrier

This complete system is mounted to a robotic arm, as illustrated in figure 4.10, where the switch sensor 1 closes the carrier and the robotic arm is tilted to an inclined angle to transport the carrier setup to the instrument tray, which is located adjacent to the robot. where the carrier is closed by the switch sensor 1 and the robotic arm is tilted to an inclined angle to take the carrier setup towards the instrument tray which is placed next to the robot. The force created by this angle makes the instrument move in between the gripping material and the platform. Once the instrument is detected by the Infrared sensor and switch 1 is closed the motor starts rotating and transmits it through a belt drive which drives the carrier towards another end until switch 2 is closed and the motor halted as shown in figure 4.11. The Infrared sensor at the handover position detects the instrument and the motor halts till the instrument is taken out by the surgeon.

4.4.2 Instruments tray

One of the key objectives of this thesis work is to create custom-designed instrument-carrying trays. This is necessary due to the specific requirements of the instrument carrier system, which grips the instruments at an angle. The purpose of the tray is to securely hold the instruments in a manner that facilitates easy picking by the carrier system. To ensure convenience and efficiency, the tray position is fixed to the robot's base frame, eliminating the need for repeated registration of the tray's position relative to the robot. The anticipated design of the tray platform is illustrated in the figure below.

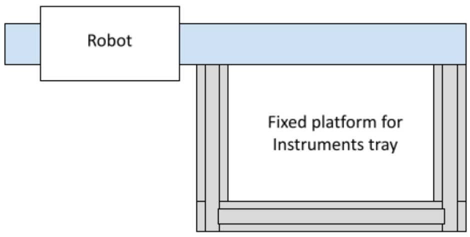


Figure 4.12: Fixed platform for instruments tray

Instrument holder

In order to prioritize the safety of surgeons during surgeries, it is common for surgical instruments to have sharp edges. Therefore, it is crucial that these instruments are grabbed and delivered in a manner where the sharp part is positioned on the opposite side, inside the instrument holder. For instance, instruments like Mosquito forceps, scalpel handles, and Mayo scissors need to be placed in such a way that their sharp edges are securely positioned inside the holder. This ensures the safe handling of the instruments during surgical procedures.

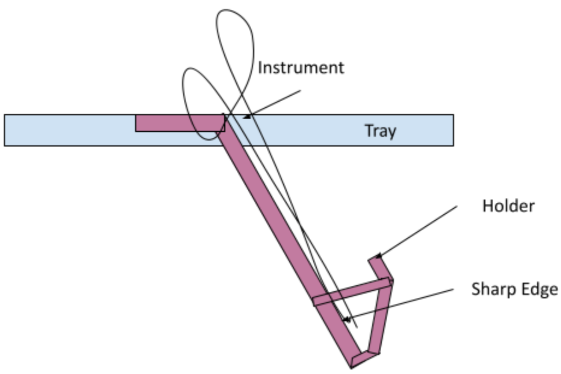


Figure 4.13: Conceptual of Instrument holder

4.5 Expected Outcomes

The key objective of this thesis is to design and test an instrument carrier system to carry the instruments from tray to surgeon with fewer moments of the robot. Some of the expected outcomes are mentioned below.

- Creating a user-friendly assembly and disassembly system using 3D-printed components designed for one-time use.
- Minimize the duration taken by the conventional gripper to hand over the instrument to less than 6 seconds.
- For grasping and carrying the instrument the carrier setup should be well-protected and closed to ensure the patient and surgeon's safety.
- Designing a low-cost instrument tray with separate instrument holders on a stationary platform.
- Implementing an offline speech recognition system to get the required instruments.

5 Implementation

In this chapter, we are going to discuss the implementation of the concepts we discussed earlier in conceptual design- 4 starting from the design of the instrument carrier followed by the instrument tray and offline speech recognition techniques.

5.1 Instrument carrier system

The design concepts of the instrument carrier systems are implemented in the following order

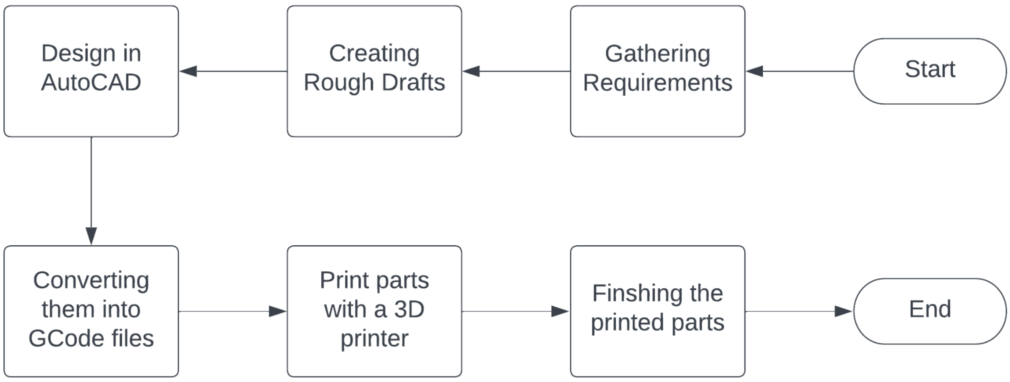


Figure 5.1: Flow chart of designing an instrument carrier system

5.1.1 Creating drafts

Initiate the process by collecting the specified requirements outlined in(chapter 4)for designing the carrier system, including its structures, shapes, and dimensions. Merge the concepts from existing designs with the system's implementation requirements. Subsequently, generate preliminary sketches to obtain a fundamental outline of the carrier system.

5.1.2 Design in AutoCAD

CAD: Computer-aided design (CAD) is a powerful tool for making precise and comprehensive three-dimensional models of objects and structures. In recent years, it has evolved into a crucial tool for designers in various professions, including architecture, engineering, and product design. CAD files may be used to generate virtual models of things and structures that can be altered and tested before being produced in reality. The widespread use of standardized file formats is another significant factor when developing CAD files for study. This may assist in ensuring that the model is easily shared and accessible by other researchers, as well as facilitating cooperation and data sharing across different research groups and disciplines. STEP, IGES, and STL are common file formats for CAD models. Apart from accuracy, it is critical to ensure that the CAD model is scalable and adaptable to various testing settings. This may entail developing many versions of the model to test various situations or conditions or constructing the model to enable simple updates and revisions.

Details of the application

- Autodesk AutoCAD2023

After completing the basic draft, design them on the workbench (as shown in figure 5.2) of Autodesk AutoCAD2023, a 3D CAD designing application that enables us to design the required parts separately. Usually, these types of files are saved as ".*dwg*" files.

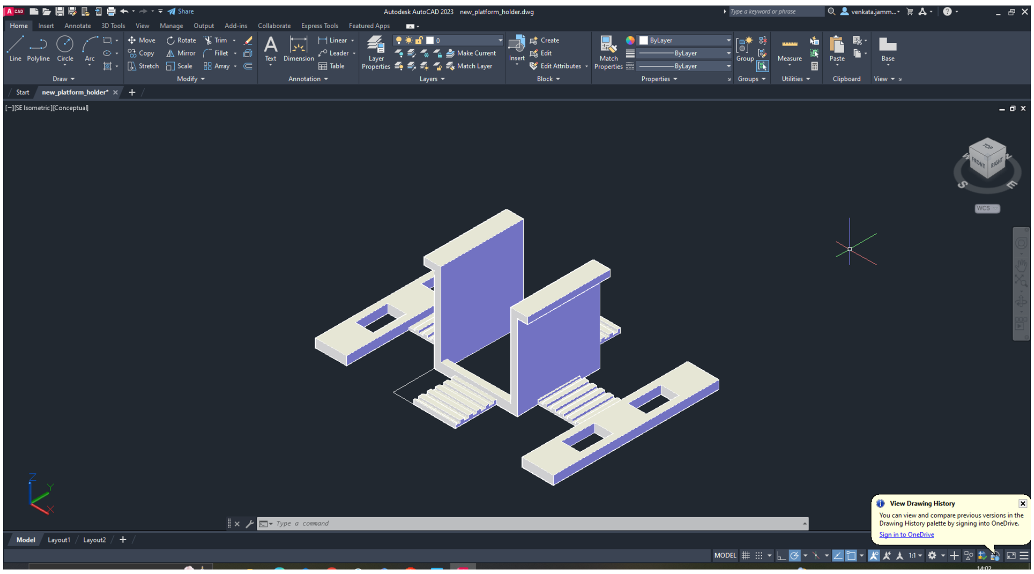


Figure 5.2: Work bench of Autodesk auto-cad2023

After completing the design those files were union and saved in STL format as shown below

```
ACAD
|__Export
      |__Other Formats
                  |__File Location/FileName/ FileType/Lithography(*.STL)
```

Figure 5.3: Saving a file in .STL format

5.1.3 Converting STL files to G-code files

We discussed converting the"*.STL*" files earlier (in figure 5.3) requires an application called "*PrusaSlicer*", A slicing application to create 3D models for printing. It is created especially for Prusa 3D printers, although it is also suitable for many other printers. Following is the step-by-step procedure of working with PrusaSlicer in detail:

1. **Open PrusaSlicer:** The first step is to open PrusaSlicer on your desktop. You can download and install it from the Prusa website[1]

2. **Load a 3D model:** You can load the saved .STL file 3D model into PrusaSlicer by clicking on the "Add" button and selecting the file from your desktop.

3. **Configure print settings:** The print settings, such as layer height, print speed, infill density, and support material, then have to be configured. You may accomplish this by clicking on the "Print Settings" menu to make the necessary changes.

4. **Slice the model:**After you've configured the print parameters, click the "Slice" button to slice the model. This process creates the G-code instructions required by the 3D printer to print the part.

5. **Preview the print:** Soon after slicing, click the "Preview" button to see a preview of the print. This shows exactly how the model will be printed layer by layer. .

6. **Save the G-code file:** Following that, once you like what you see with the preview, click the "Export G-code" button to export the G-code file. This file may then copy onto a SD-card and insert into the 3D printer to be printed.

[1] https://www.prusa3d.com/page/prusaslicer424/

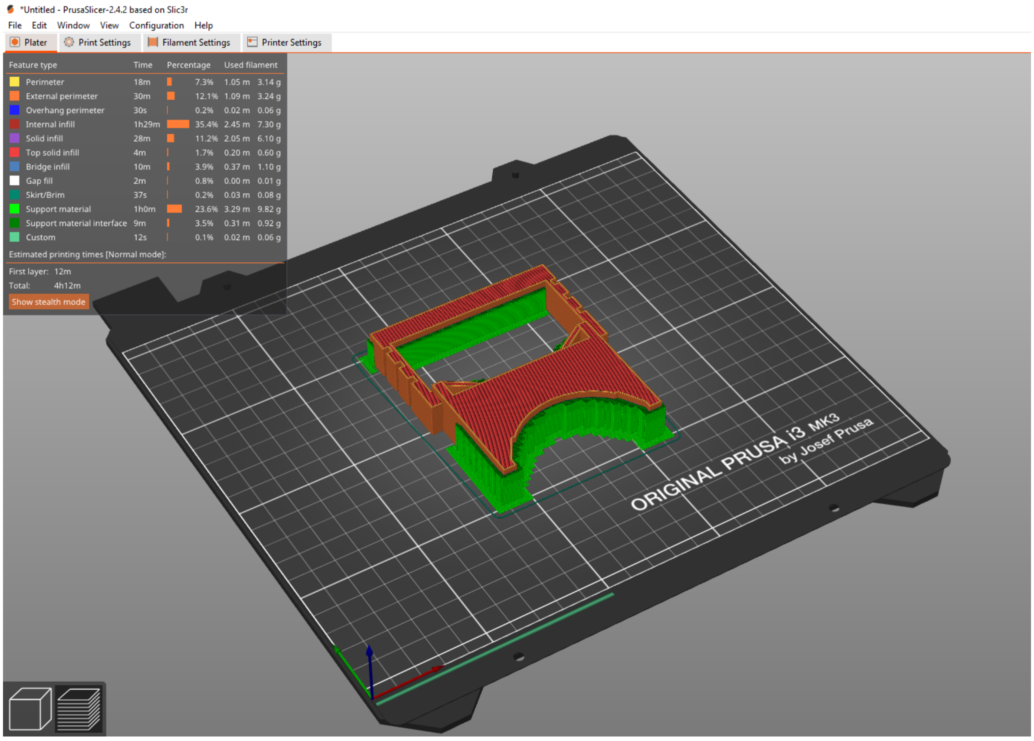


Figure 5.4: Slicing a part in PrusaSlicer

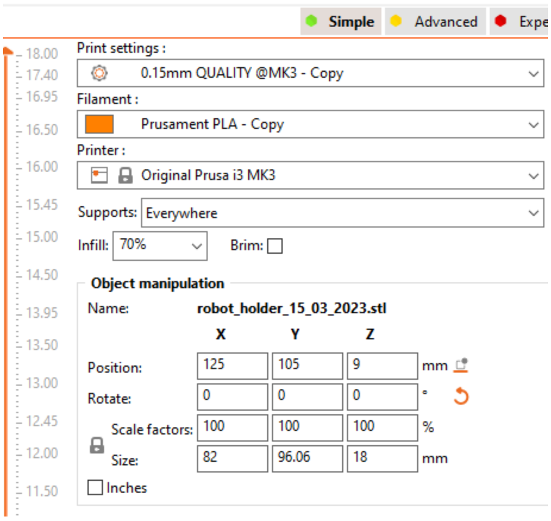


Figure 5.5: Print settings

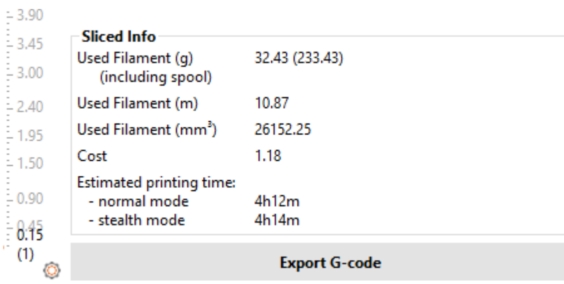


Figure 5.6: Sliced Info

5.1.4 Printing parts in 3D printer

Once the G-Code files are created they can export to an SD card and insert into the SD-card slot provided with the Prusa 3D printer as shown in the below figure and follow the steps

1. **Load filament:** The common filament material's are PLA, PETG, PC(Polycorbonate), Flex, PVB and PA(Nylon). Among them, PLA and PETG are the popular ones which were used by us. For loading the filament select the load filament option on the display screen of the prusa slicer and the filament attached as shown in the below figure

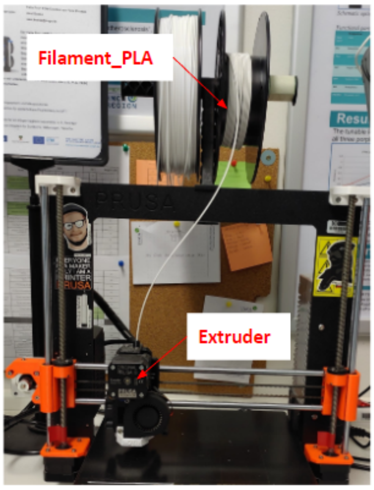


Figure 5.7: Loading filament in PrusaSlicer[2]

2. **Pre-heating the bed:**Preheating the bed in Prusa Slicer (or any other 3D printing software) is critical for ensuring that your 3D prints stick nicely to the build plate and are not affected by warping or other flaws.

   When you initiate a print, the printer warms both the extruder (the portion that melts and deposits the filament) and the build plate (the flat surface on which the print is constructed). By preheating the bed, you let the build plate achieve its ideal temperature before the start of the print. This ensures that the first layer of filament sticks properly to the plate and remains in place while the rest of the print is constructed. Diverse filaments and printing materials imply various bed temperatures. Pre-heating the bed lets you establish the proper temperature for your individual filament or material, preventing warping or other problems in the final print.

[1]Image taken from Inno Lab-Inka, OVGU, Magdeburg

In general, pre-heating the bed is an essential step in the 3D printing process and plays a role in the quality of your prints.

3. **Select the file and print:** Finally, select the file and start printing. The final output will be looked as below

Figure 5.8: 3D-Printed Parts[3]

5.1.5 Finishing the printed parts

Some parts with complex shapes and structures required support material while printing. After printing this support material has to be removed (as shown in figure 5.9). If the final parts are deformed due to external conditions then it has to be reshaped by using a filer and for screwing some parts tapping them is required (as shown in figure 5.10).

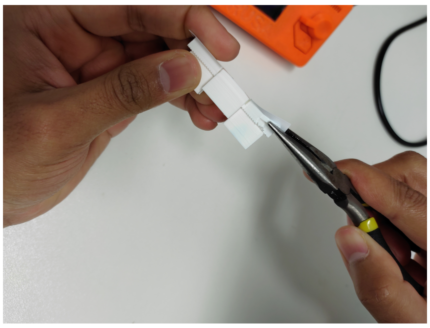


Figure 5.9: Removing support material[4]

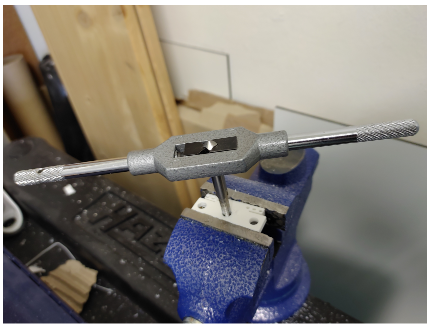


Figure 5.10: Taping[5]

After printing the required parts they are going to assemble according to the concepts discussed in the previous chapter 4.4.1

5.1.6 Concept-1: Closed conveyor system on rollers with fixed platform

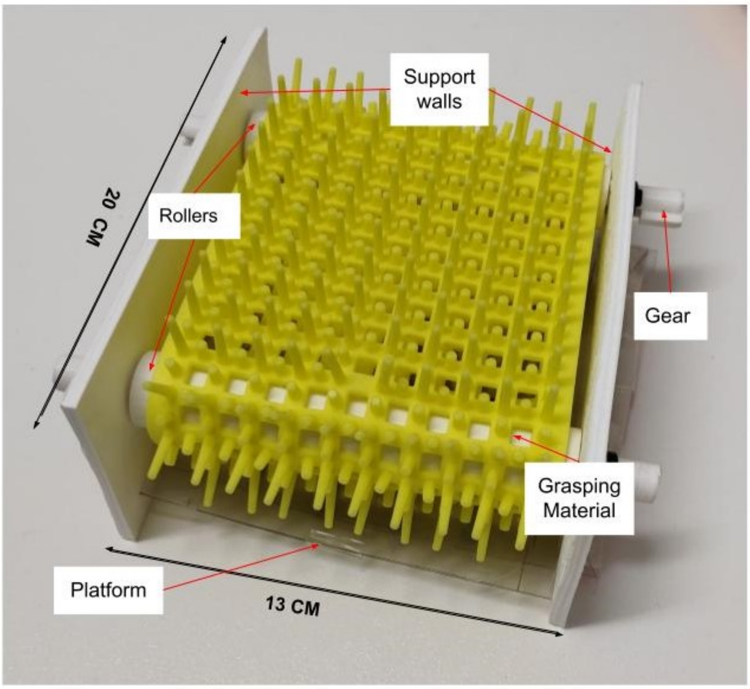


Figure 5.11: Instrument Carrier Concept-1

By working on different concepts of instrument carriers, An initial design is implemented as concept-1 (asshownw in figure 5.11). This carrier system is of dimensions 20 CM x 13 CM and is made up of several 3D-printed pieces, including rollers, support walls, and gears. Furthermore, it has a gripping material and a PC glass platform[6]. The gear connected to the roller was helping the device in grabbing the instrument from one of its ends and smoothly collecting it with the help of rollers, transporting the instrument to its second end at the handover position. Testing this carrier several times some of the drawbacks were discussed below.

- The friction between the grasping material and the rollers made inconsistent movements.
- The torque required by the motor to rotate the rollers is more and it makes the instrument throw away from the system.
- These high movements made the support walls unstable.

Taking these setbacks into consideration, an upgraded system(Concept-2) was designed and we are going to discuss it in the next section.

[5]https://dental-instruments.bbraun.com/p/PRID00006266
[6]https://www.amazon.de/Polycarbonat-Platte-transparent-PC-alt-intech

5.1.7 Concept-2: Movable carrier system with a platform

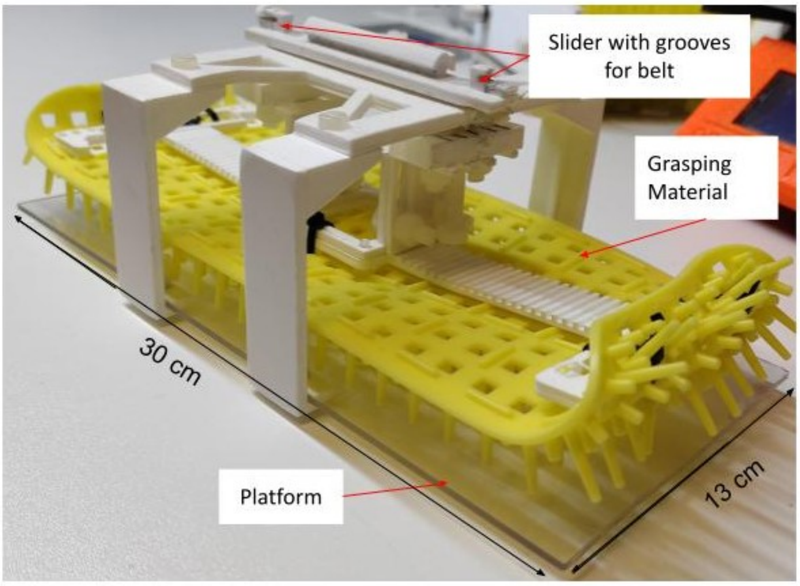


Figure 5.12: Instrument Carrier Concept-2

An updated design to the previous one is this concept-2 (as shown in figure 5.12). The carrier system is 30 cm x 13 cm in size and is made up of multiple 3D-printed components namely, Slider with grooves, supported legs, frame to hold grasping material. Additionally, a gripping material 5 and a PC glass platform6. The working principle is simple as we saw earlier, the grooves provided to the slider attached to the ends of a timing belt. The belt is driven by a stepper motor to and fro in between the switch sensors for transporting the instrument. After conducting different experiments (which will discuss in detail in the next chapter), some issues are derived as discussed below.

- This system is complex to assemble and disassemble because of more number of screws.
- The initial torque required by the motor to start the carrier from the idle position is higher due to the combined weight of the carrier, support legs, grasping material and platform
- The added weight of this system increases the tension of the timing belt.
- This damages the slider grooves which are attached to the timing belt.

Taking these setbacks into consideration, an upgraded system(Concept-3) was designed and we are going to discuss it in the next section.

5.1.8 Concept-3: Carrier system with a movable carrier on a stationary platform

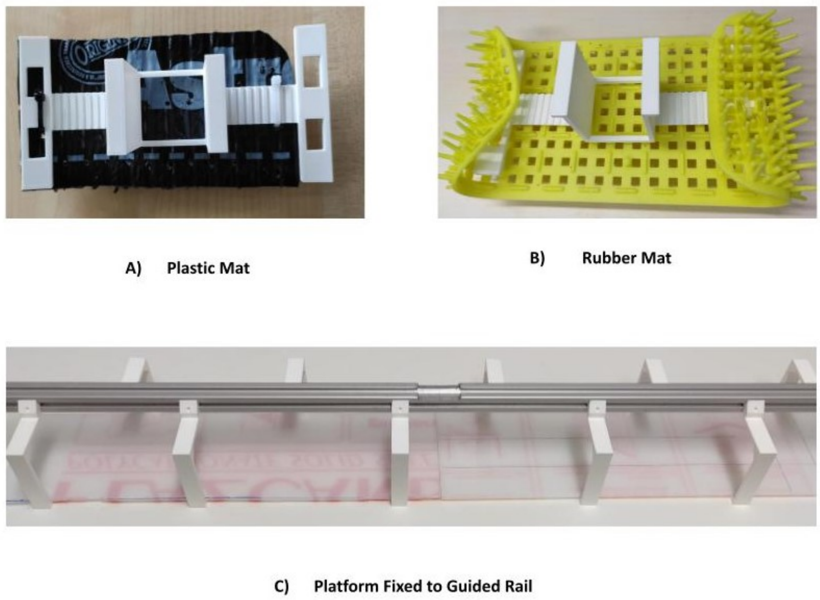


Figure 5.13: Instrument Carrier Concept-3

The Instrument Carrier Concept-3 (as shown in figure 5.13), represents an enhanced iteration compared to the previous Concept 1 and Concept 2. This upgraded version addresses previous setbacks by presenting a simplified design with a reduced number of supported parts. In contrast to the platform showcased in (figure 5.12), the carrier system now features a separated platform that is securely fixed to a guided rail, providing an increased length. Furthermore, the attachment mechanism between the slider and grasping has been simplified, eliminating the need for screws. In addition, two different materials, Plastic and Rubber, have been utilized to conduct tests on the instrument's grasping capabilities. A comprehensive discussion on the complete assembly of this carrier system will be presented in the subsequent chapter, referenced as [6].

Some of the advantages of this concept compared to the other two are discussed below,

- The absence of screws in the design of this system allows for easy assembly and disassembly.
- The removal of various parts connected to the carrier has resulted in reduced torque requirements for the motor when initiating movement from the idle position.
- The slider, carrier, and platform are each separate entities, functioning independently of one another.

5.1.9 Reason behind selecting this design

As mentioned earlier, the conceptual design chapter outlines a set of requirements. This section elaborates on the reasoning behind the design choices and illustrates how the proposed solution effectively meets all of these requirements.

Factors influencing the selection of the materials

Rubber mat is chosen for its high-friction surface, which enhances the grip on the instruments. Its excellent traction properties prevent slippage and ensure a secure hold during transportation. The flexibility of the rubber material allows it to conform to the shape of the instruments, providing additional stability and reducing the risk of accidental dropping.

Plastic mat serves as a protective layer for both the instruments and the underlying surface, which is typically a poly-carbonate glass plate. The smooth surface of the plastic mat enables easy sliding and movement of the instruments, facilitating their efficient handling.

Polycarbonate glass is an ideal material choice due to its excellent transparency, high impact resistance, and smooth surface. The smooth surface of the polycarbonate glass plate reduces friction, enabling effortless sliding of the instruments during the gripping and transportation process.

Additionally, during the evaluation of these mats, it was observed that the rubber mat generates additional friction when sliding on a glass plate, whereas the plastic mat glides smoothly with minimal resistance. Consequently, the decision was made to opt for the plastic mat, as it offers a seamless sliding experience after slight trimming, making it the preferred choice over the rubber mat.

Designing Carrier with a guided rail of 80cm

The entire carrier system is attached to a slim and lightweight guided rail (measuring 80cm X 2cm). The design objective was to achieve a distance of approximately 1 meter from the instrument to the surgeon. To achieve this, the instrument carrier covers 80cm of the distance, while the remaining distance is covered by the robot's movements. This combination effectively minimizes both the robot's movements and the overall time required to transfer the instrument from the tray to the surgeon.

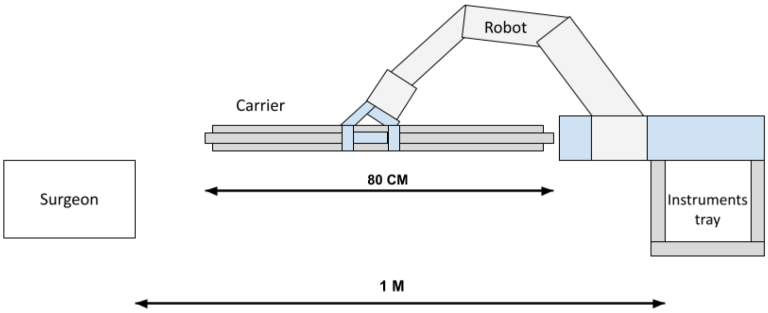


Figure 5.14: Distance from instrument table to the surgeon

Dimensions of the carrier

The requirement for a carrier size of approximately 8-12 cm in length and 8 cm in width is satisfied to ensure the safe transfer of instruments without collisions with the carrier's protective walls, considering that the maximum dimensions of the instruments listed are 24 cm in length and 7.5 cm in width.

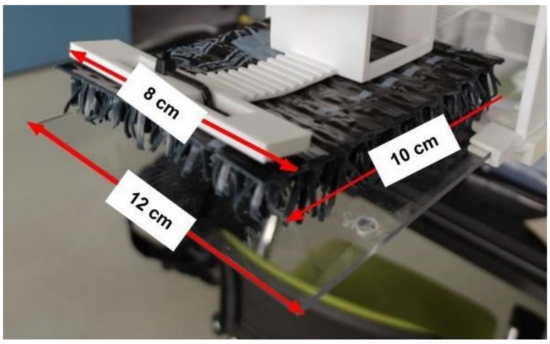
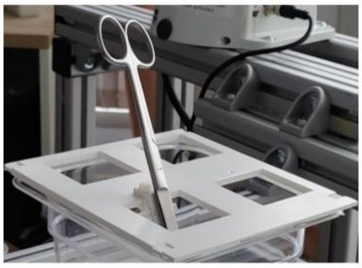


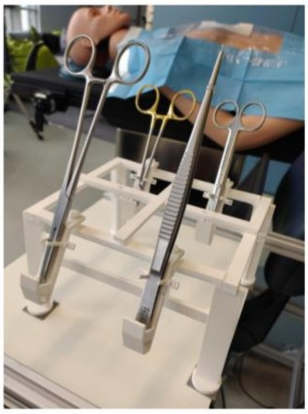
Figure 5.15: Length and Width of the carrier

5.2 Instruments tray

As mentioned previously, the development of a specialized instrument tray that can securely hold the instruments for efficient grasping by the carrier is a key objective of this thesis work. In order to achieve this goal, a cost-effective approach was adopted for designing the instrument tray. Extensive research was conducted to analyze various tray concepts available in the market, leading to the implementation of two distinct tray designs, both of which are shown in figure 5.16.



B) Tray Plate mounted on jar



B) Tray with adjustable holders

Figure 5.16: Instrument Tray-Concept

Instrument Holder

The instrument holder has been designed in such a way that the adjustable slider with screws attached to it can be easily altered to accommodate various instrument shapes and sizes, as seen in the picture below.

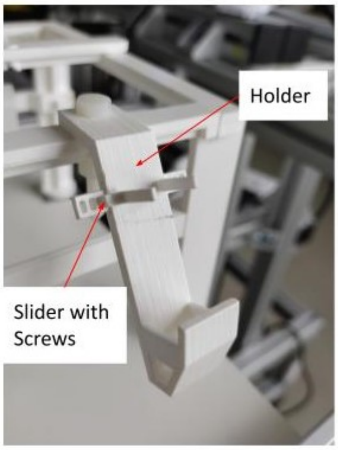


Figure 5.17: Instrument Holder

The design concept for the instrument holder is illustrated in figure 5.18. The holder is tilted at an angle X from the tray platform, this X is selected from conducting an experiment with different angles(30,45,60,90 degrees) out of which X = 60 deg ensures that the instrument within remains intact with the surface of the holder. Additionally, the end of the holder features a reversed "$J - shape$" effectively preventing longer instruments from falling backwards. This design not only ensures instrument stability but also generates a natural counterforce while gripping the instrument, resulting in a smooth passage of the instrument within the carrier.

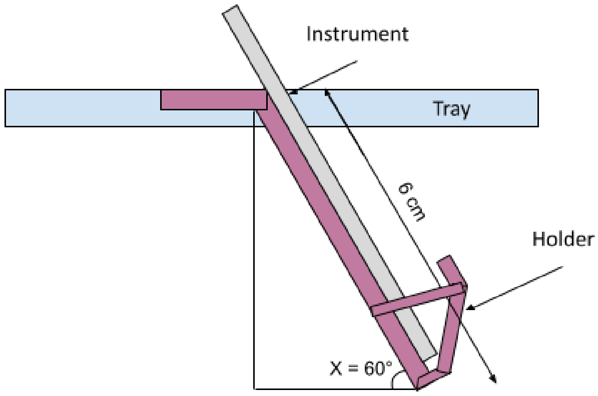


Figure 5.18: Concept of Instrument Holder(X = Angle of inclination)

Platform for the instrument tray

The instrument tray platform, measuring 49cm X 24cm, consists of a cardboard platform with fixed guided rails on the same base as the robot. This design eliminates the need for tray registration each time the handover position is changed, simplifying the overall process.

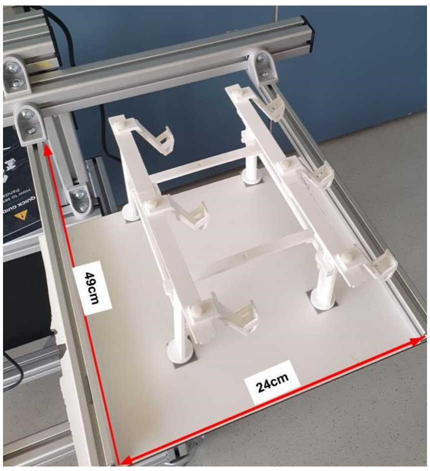


Figure 5.19: Platform for the instrument tray

5.3 Offline speech recognition model

The most popular offline speech-to-text recognition open-source speech recognition toolkits are Pocketsphinx and Vosk. The implementation and working with this model are discussed below.

5.3.1 Vosk model:

Vosk is a publicly accessible voice recognition toolkit that enables you to build speech-to-text models that can function without an internet connection. To utilize Vosk, you must first train a speech recognition model on the exact type of voice data you wish to transcribe. This may be accomplished using Vosk's model training tools or by applying pre-trained models for specific languages and dialects.

To Build a model with Vosk follow these steps:

1. To install Vosk, follow the installation guide provided here[[7]].
2. Download the language model from [[8]]
3. For taking the speech input by a microphone (provided), PyAudio[9] has to be installed.
4. To recognize the spoken words KaldiRecognizer need to be installed(if not installed with Vosk).

operating system: Ubuntu-20.4

The Vosk code(Python) works without any errors and the recognized words are based on the model chosen. By following this "$Updating - words - and - the - vocabulary - in - the - big - models$" guide[[10]] Replacing "$words.txt$" file in the "$Vosk/vosk - model - small - en - us - 0.15$" folder provided by Vosk with "$My - Instrument - Names.txt$" file containing the list of the names of the instruments.

Drawback: For updating the words and vocabulary large amount of training data including larger files of audio recordings and text files are required. Due to this reason, Further implementation with Vosk is not possible.

After an unsuccessful attempt at implementation with Vosk, another speech recognition model using Pocket-Sphinx will be discussed in a further section.

5.3.2 Pocketsphinx model:

PocketSphinx was implemented by Carnegie Mellon University, an open-source voice recognition framework. It was created to work offline, which means it does not require an

[7] https://alphacephei.com/vosk/install
[8] https://alphacephei.com/vosk/models
[9] https://pypi.org/project/PyAudio/
[10] https://alphacephei.com/vosk/adaptation

internet connection to operate. An offline speech-to-text model, that can transform spoken transcriptions into text using a pre-trained model without requiring internet access.

Pocketsphinx recognizes speech using Hidden Markov Models (HMMs). HMMs are statistical models for modelling temporal sequences such as speech syllables Pocketsphinx's HMMs are trained on a vast dataset of speech recordings and transcriptions and may be fine-tuned for specific applications or activities.

- **Install:**For installation follow the guide[[11]]
- **Operating System:** Ubuntu-20.4

The following are important steps to work with Pocketsphinx,

1. **Creating corpus file:**

   A corpus file is a significant and organized group of written or spoken texts used as a framework for statistical analysis and language modelling in natural language processing (NLP). A corpus file is often used to train machine learning algorithms like language models and text classifiers and for gathering linguistic information like word frequency, syntactic patterns, and semantic correlations. A corpus file can be created in a variety of ways. Manually compiling a collection of texts into a text editor or spreadsheet is one method. This is costly and time-consuming, but it gives you more control over the corpus's content and quality. Another approach is to automatically utilize web scraping tools or APIs to collect text data from web pages or other online sources. This approach is quicker, but the corpus produced may be less consistent or meaningful.

   The first step in creating a corpus file is to create a plain text file with the required list of words and by using an API called Sketchengine [[12]] one can create the corpus file.

2. **Converting Corpus to ".*dic*" and ".*lm*" files:**

   The ".*dic*" and ".*lm*" are called dictionary and language model files. A.dic file (dictionary) provides a collection of words and their pronunciations. A.lm file (language model) is a statistical model that evaluates the probabilities of a particular sequence of words appearing in a language.

   To convert the corpus into dictionary and language model files by using an API called Sphinx Knowledge Base Tool[[13]]

   Select the "$choosefile$" option in the API[13] then upload the corpus file (generated in the previous step) and click compile knowledge base, A file(for example

[11] https://pocketsphinx.readthedocs.io/en/latest/
[12] https://www.sketchengine.eu/
[13] http://www.speech.cs.cmu.edu/tools/lmtool-new.html

"$TAR5322.tgz$") will be generated. Extract all the files from the .tgz folder to the location where the language model of Pocket-sphinx as shown in figure 5.20.

Figure 5.20: Pocketsphinx model folder

3. **Run the command in the terminal:** For recognising the speech continuously, the pocket sphinx continuous mode is used. It recognizes spoken words by first gathering audio input from a microphone or other audio source and then processing it instantaneously. It converts an audio input into a series of phonemes, which are the basic units of sound in a language, using an acoustic model. After that, the phoneme sequence is integrated with the language model to provide the most likely sequence of words said by the user.

   The following command will be executed in the terminal in the order of Model name(`pocketsphinx_continuous`), Microphone(-inmic yes), Hidden Markov Model(-hmm), the path for sphinx pre-defined language model(en-us), your language model (-lm /path), your dictionary file(-dict /path) then press enter. For example, see the picture below.

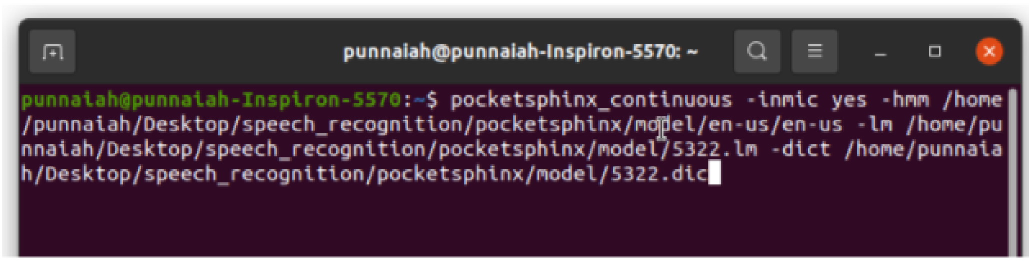


Figure 5.21: Pocketsphinx continuous

After running the above command the microphone is enabled and ready to take the input as speech from the surgeon as follows

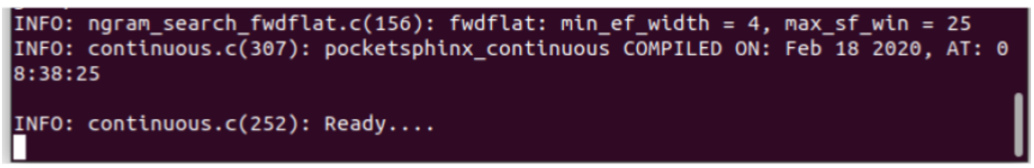


Figure 5.22: Microphone ready to listen

When the surgeon requests an instrument to be picked (Example: Mayo scissors), the words are recognized and the result displays on the screen as shown below in figure 5.23, and the microphone is ready to hear further input continuously until the program is terminated.

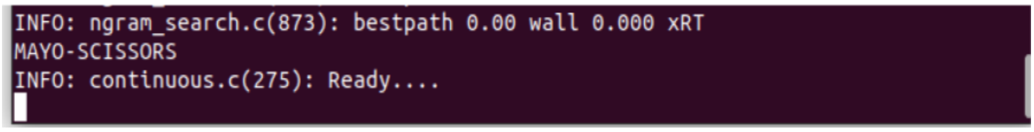


Figure 5.23: Output as text

The step-by-step procedure of developing this implementation as an experimental setup in an operation room scenario will be discussed in the following chapter[6]

6 Experimental Setup

This chapter discusses the detailed procedure of the experimental setup starting with the operation room scenario, the required 3d-printed parts and how they are assembled, and their selection criteria followed by the working principle.

6.1 Operation room scenario

The typical setup in an operating theatre includes an operating table for the patient, a cobot equipped with an instrument carrier system, an instrument tray, and a microphone to capture the surgeon's input. This arrangement would appear as follows,

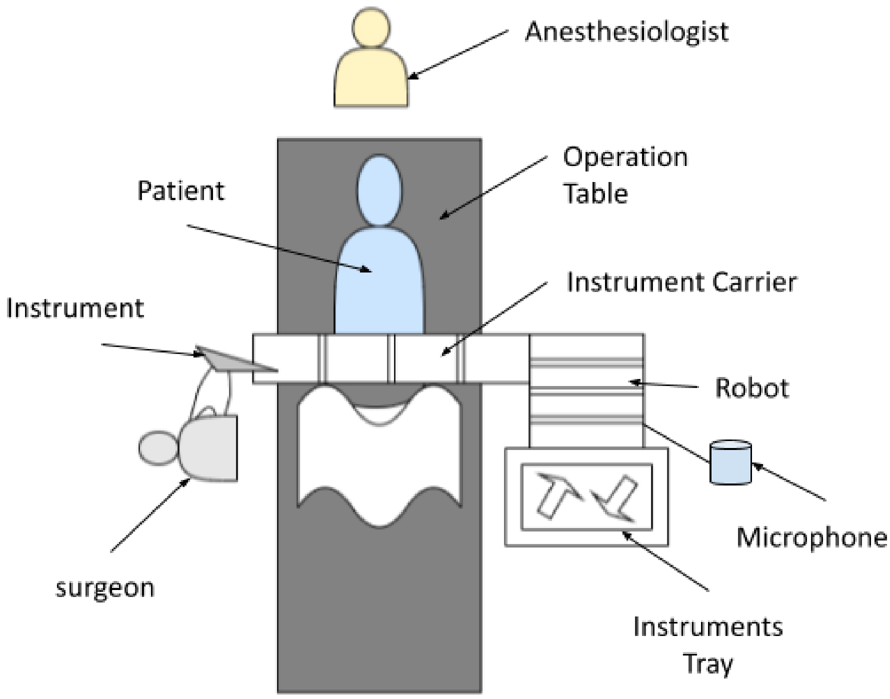


Figure 6.1: Operation room scenario

6.2 Instrument carrier Setup

The instrument carrier system (shown in figure 4.9), is constructed by assembling several 3D-printed components along with additional parts listed in table 6.1.

S.No	Part	Quantity
1	Linear guided rail	1
2	PC glass plate	1
3	Carrier holder	1
4	Slider	1
5	Support legs	12
6	Leg caps	12
7	Robot holder-round	1
8	Extension of robot holder	2
9	Robot holder legs	8
10	Motor mountings	2
11	Switch holders	2
12	Support walls	12
13	Pulley Holders	2
14	Plastic or Rubber mat	1
15	GT2-Timing belt-5mm	1
16	Pulleys	3

Table 6.1: Required parts for instrument carrier setup

Steps involved in the assembly procedure of the carrier setup.

1. At first, the linear guided rail of length 80cm is taken and at the midpoint it has to be reshaped as shown in the below figure to mount the stepper motor.

2. After that, the timing belt is inserted in the groves of the guided rail. The ends of this belt are screwed to the grooves of the slider inserted at the bottom of the rail.

3. Then the carrier holder fitted with a plastic or a rubber mat is inserted into the slider and the motor mountings were fitted at the reshaped part of the guided rail.

4. Now, the heads of the support legs are screwed to the slider's side groves, and the bottom surface holds the PC glass plate platform fitted by leg caps. The support walls that prevent the instrument from slipping from the carrier are attached between these support legs.

5. Finally, This entire setup is attached to the robot with the help of a holder and support legs. Additionally, other holders were made to maintain the balance of the guided rail.

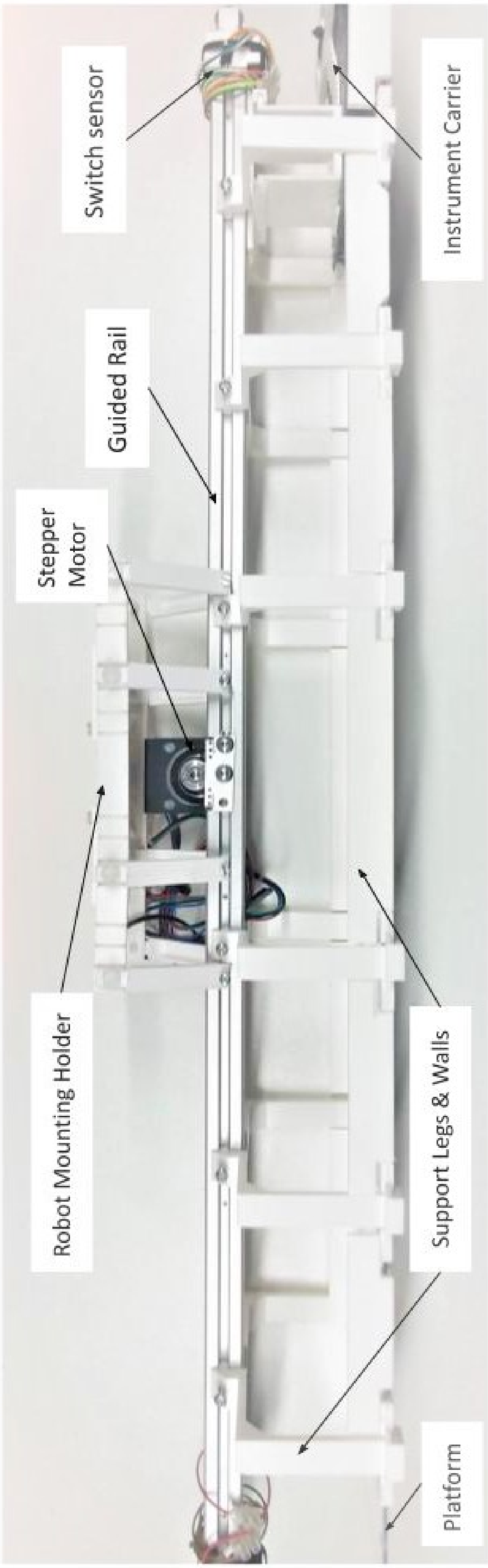


Figure 6.2: Instrument Carrier system-3

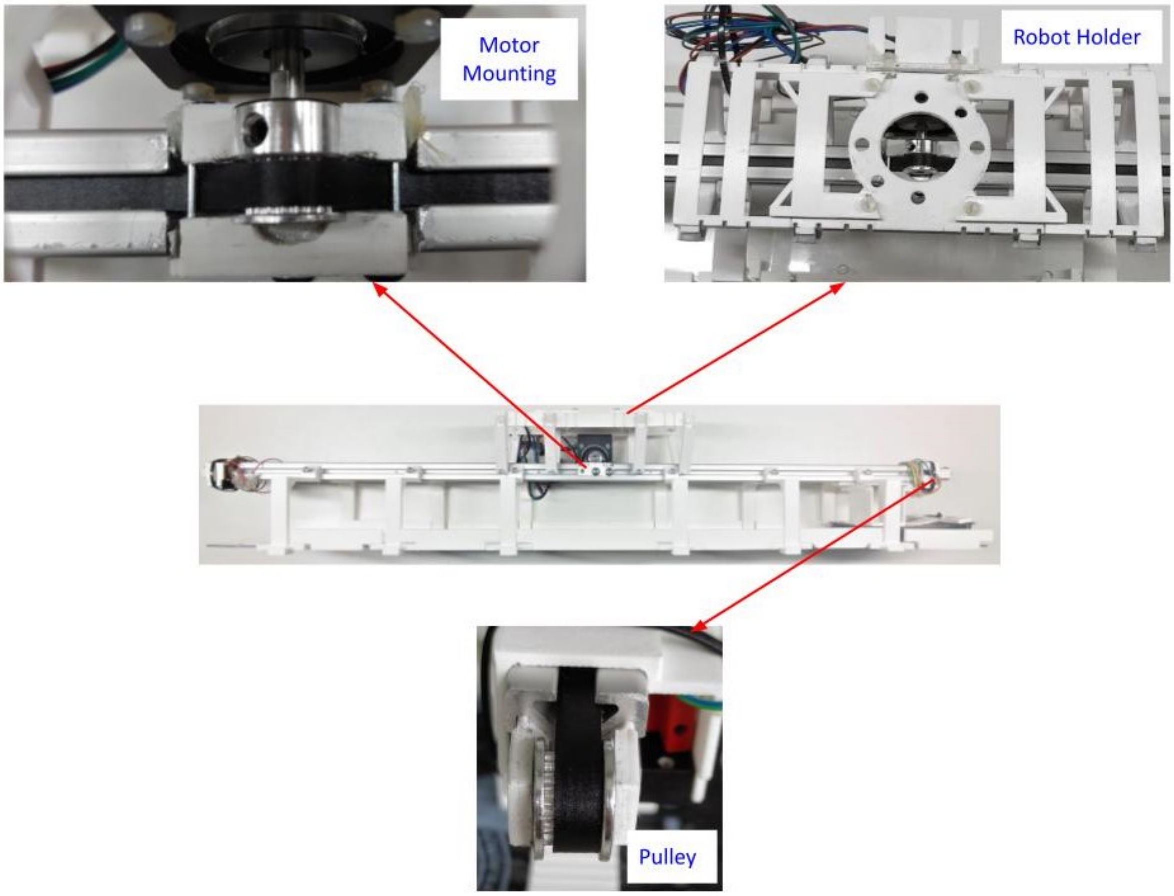


Figure 6.3: Motor mounting, Robot holder and Roller

In figure 6.3, the motor mounting is a crucial design element aimed at ensuring smooth belt operation with minimal friction between the belt and the guided rail surface. To prevent belt misalignment and twisting, the pulley on one side of the rail has been carefully trimmed.

6.2.1 Drive system for instrument carrier setup

The driving system of the carrier incorporates a comprehensive setup that utilizes a timing belt to drive the instrument carrier. The necessary components for this system are illustrated in table 6.2.

S.No	Item	Quantity
1	Stepper Motor	1
2	Arduino-UNO	1
3	Switch Sensor	2
4	Infrared Sensor	1
5	Pololu A4988 Stepper Motor Driver	1

Table 6.2: Drive system for instrument carrier setup

For selecting the motor a "$Load - Torque$" test has been carried out by considering some parameters like the total weight of the carrier setup, length of the timing belt and length of the guided rail. The result of this test shows the motor required is of torque around 22-24 Ncm. The motor used here is a Nema 17 stepper motor [1], satisfies the required parameters also stepper motor is known for its accuracy. To detect the instrument at the handover end of the carrier, an infrared sensor is positioned beneath switch-02. When both switch-02 is closed and the infrared sensor detects the presence of an object, the motor operation is halted until the surgeon removes the instrument. This combination ensures that the motor remains paused until the instrument is taken out by the surgeon. The circuit connection of the setup is shown below

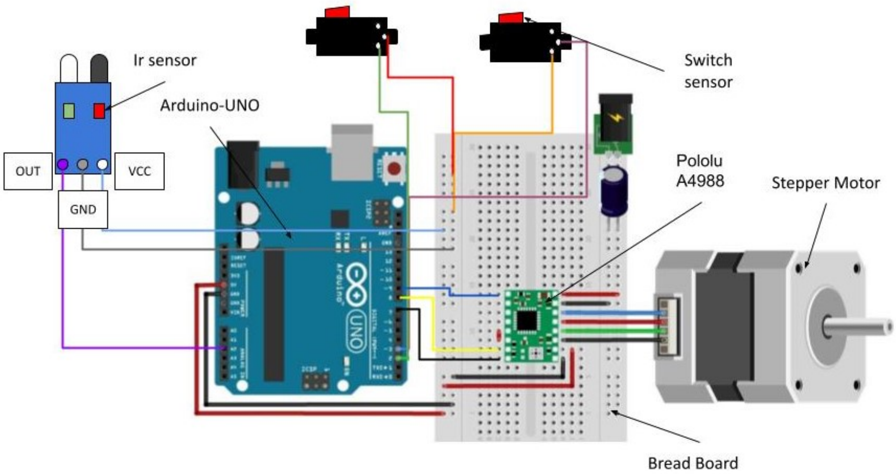


Figure 6.4: Circuit connection(source:motor,breadboard,UNO)[2]

6.2.2 Weight of entire carrier system

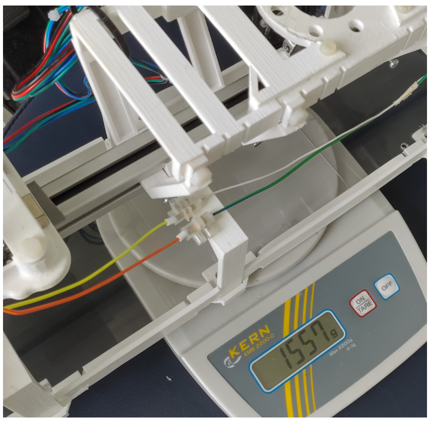


Figure 6.5: Total weight of the instrument carrier system

[1]https://www.amazon.de/-/en/gp/product/B00PNEQ9T4/ref=ewc_pr_img_1?smid=ABVRCUH7Y5NVN&psc=1
[2]https://www.makerguides.com/a4988-stepper-motor-driver-arduino-tutorial/

The fulfilment of another requirement is evident by ensuring that the total weight of the entire carrier system, including the motor drive and attached switches, is 1557 grams. This weight is lower than the robot's payload capacity, which is 3 kilograms.

6.3 Instruments tray

The specified parts listed in the table are used to assemble the instrument tray. The instruments are securely placed within the holder, and the slider is equipped with pins to prevent any lateral sliding of the instruments.

S.No	**Part**	**Quantity**
1	Tray legs	4
2	Beams for holder	4
3	Connector for beams	2
4	Support beams	2
5	Legs support	4
6	Instrument Holder	6
7	Sliders and pins	6,12

Table 6.3: Required parts for instrument tray setup

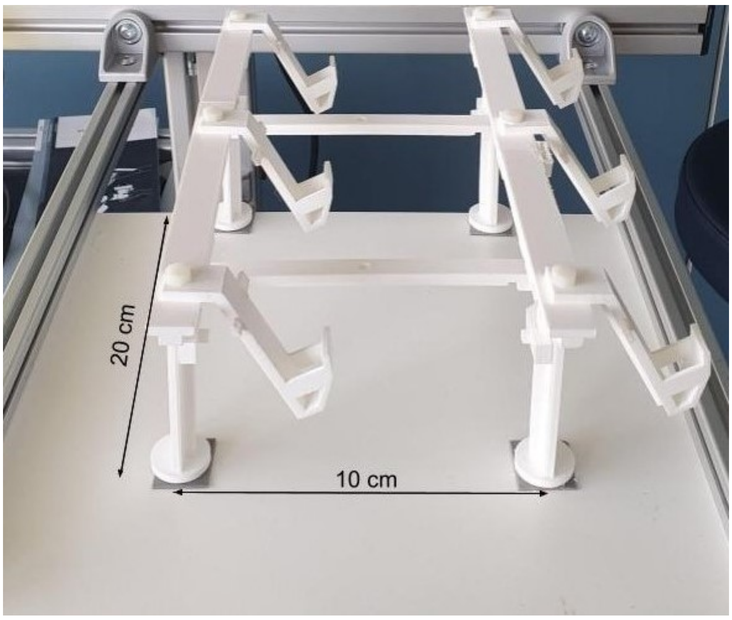


Figure 6.6: Instrument tray setup

6.4 Experiments:

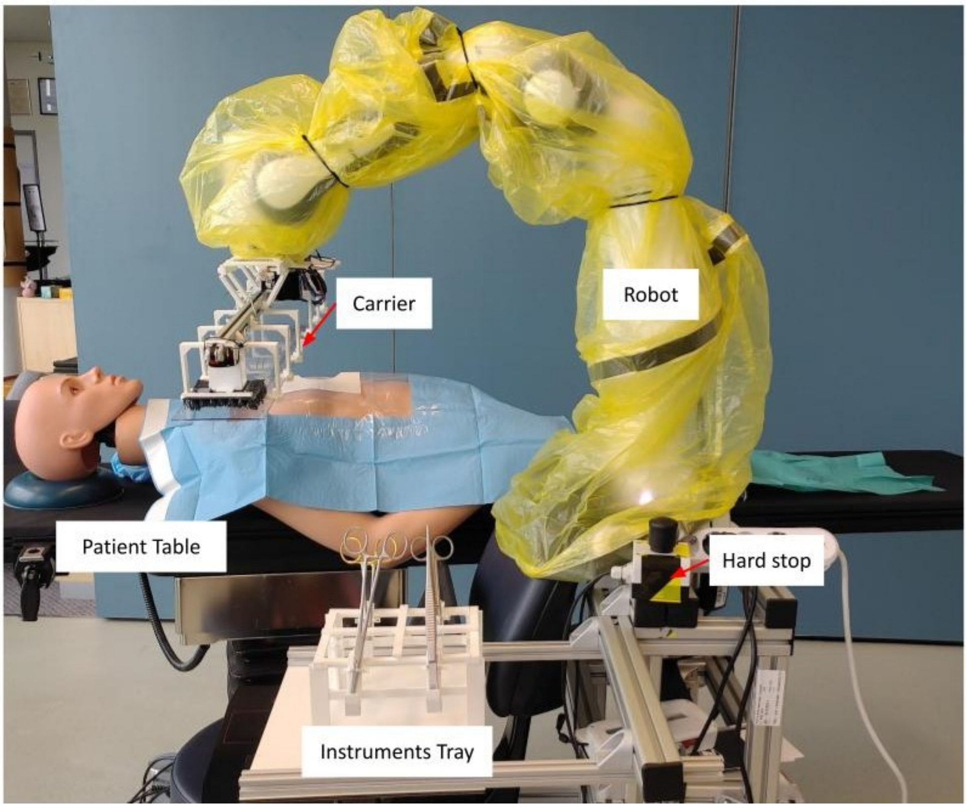


Figure 6.7: Carrier, Robot and Tray Setup

The experimental setup consists of an Instrument carrier system attached to a Franka-Emika panda robot as shown in the above figure 6.7. A specially designed instrument tray is placed next to the frame of the robot to carry the required set of instruments. Also, a hard stop is attached to the robot to stop it in unseen forced conditions.

Step-by-step procedure of the working principle:

- At first, the nurse or other assistant checks the instruments required for surgery and places them in the designated slots on the instrument tray.
- Next, the surgeon will set the handover position of the robot.
- Then, asks for the required instrument. The positions of every instrument are pre-determined by using a CSV file.
- For example the surgeon asks for ("$CURVEDFORCEPS$") then the microphone in the setup recognized the words and converted them as text(by Sphinx speech recognition) which is the input for the Robot operating system(ROS)
- Then the robot moves to the position of the instrument and pick it. Once the instrument is "IN" at (end-1) of the carrier (figure 4.4) the motor drives the carrier

towards the other (end-2) "*OUT*" (figure 4.5). In the meantime, the robot arm moves to the pre-defined handover position and waits for the surgeon to pick up the instrument from the carrier.

Note: The process of retrieving the instrument from the surgeon after its use is not addressed in this study and will be a topic for future work.

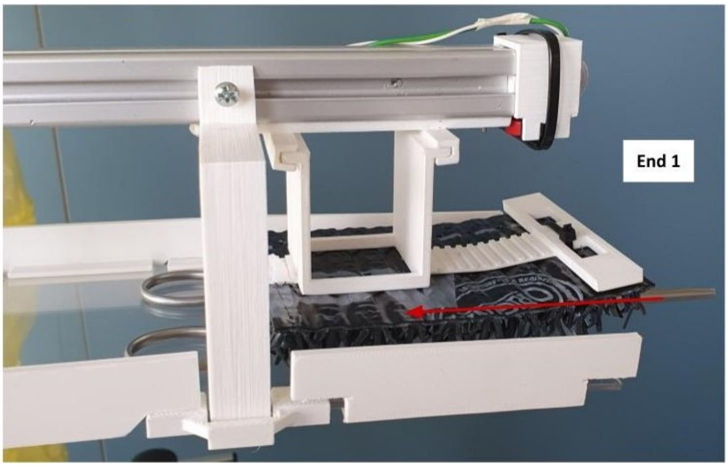


Figure 6.8: Instrument IN

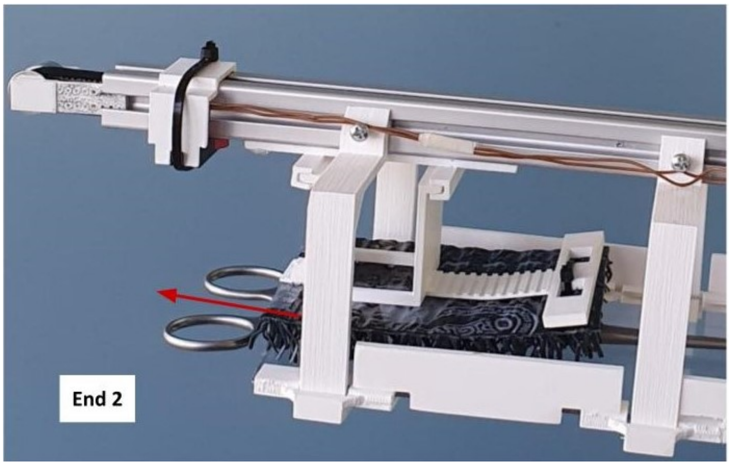


Figure 6.9: Instrument OUT

Furthermore, the sequential tasks involved in this process are executed in a specific order: speech recognition, robot movement, and carrier operation. Python is used for implementing the speech recognition system and Robot Operating System (ROS) functionalities. On the other hand, the carrier-driven motor code is developed in C++ for Arduino. A library called "*Serial.py*" is utilized to facilitate communication between these platforms. This library ensures smooth communication between the Python code and the Arduino board, simplifying the overall process. The outcomes of these experiments will be elaborated in the subsequent chapter.

6.5 Test Protocols

The test protocols of this thesis work are structured as objective, equipment, procedure and recording the results.

6.5.1 Instrument carrier system

- **Objective:**

  To measure the time taken by the instrument carrier to transfer instruments at different positions.

- **Equipment:**

  Instrument carrier system, set of instruments, Timer

- **List of instruments used:**

Sponge forceps	Curved forceps	Straight forceps
Mosquito forceps	Hysterectomy forceps	Suture forceps
Peritoneum forceps	Needle holder	Probe with eye
Army retractor	Mosquito clamp straight	Delicate forceps
Dental needle forceps	Scalpel handle	Anatomic forceps
Needle nose spring clamp	Surgical Scissors	

Table 6.4: Set of instruments

- **Procedure:**

  1. Set up the instrument carrier at the normal (180 degrees) position.
  2. Place the instruments on the carrier.
  3. Start the stopwatch or timer(here added a code to measure time with Arduino).
  4. Measure the time taken by the carrier to transfer the instruments to the end-2 position.
  5. Record the time.
  6. Repeat steps 1-5 for the carrier positions at an angle of inclination of 30 degrees and 60 degrees.
  7. Each instrument is tested more than 10 times and the results are discussed in the next chapter.

- **Data Collection:**

  Record the average duration (in seconds) for each carrier position.

6.5.2 Speech recognition system efficiency

- **Objective:**

  To evaluate the working efficiency of the speech recognition system for instrument name recognition.

- **Equipment:**

  Microphone, Instrument names list

- **Name of the instruments**

Army retractor	Arterial forceps curved	Arterial forceps straight
Babcock forceps	Curved scissors large	curved scissors small
Delicate forceps	Director with tongue	Dissection forceps
Grasping forceps	Homeostatic forceps	Sponge forceps
Mayo scissors	Needle holder large	Needle holder small
Peritoneum forceps	Probe with eye	Retractor large
Mosquito forceps	Retractor small	Scalpel handle large
Scalpel handle small	Small forceps	Large forceps
Stitch scissors	straight scissors	suture forceps
Tissue forceps large	Tissue forceps small	Vein retractor

Table 6.5: List of instruments

- **Procedure:**

  1. Set up the microphone near the robot.
  2. Utter the instrument names from the list into the microphone, ensuring clear and complete pronunciation. (from a distance of 10 cm to 1 meter from the microphone)
  3. Record the number of correctly recognized instrument names.
  4. Repeat steps 2-3, twenty times for each instrument name, varying the order of utterance.
  5. Repeat steps 1-4 in a noisy environment too.

- **Data Collection:**

  Record the number of recognized instrument names for each instrument.

  Note: This system is tested by 12-15 different people of age groups (19-32) and with online voice chat-bots as well.

7 Results

The results of this thesis work are discussed in detail. starting from the time taken by the instrument carrier to transmit the instrument at different positions along with the efficiency of the spoken as well as their respective recognized words and the other production costs of the complete system.

7.1 Instrument carrier system

The time taken by the instrument carrier to transfer the instrument starting from the end-1 position to end-2 is calculated by placing the carrier at three different positions

1. At normal(180 degrees) position
2. At an angle of inclination(30 degrees) position
3. At an angle of inclination(60 degrees) position

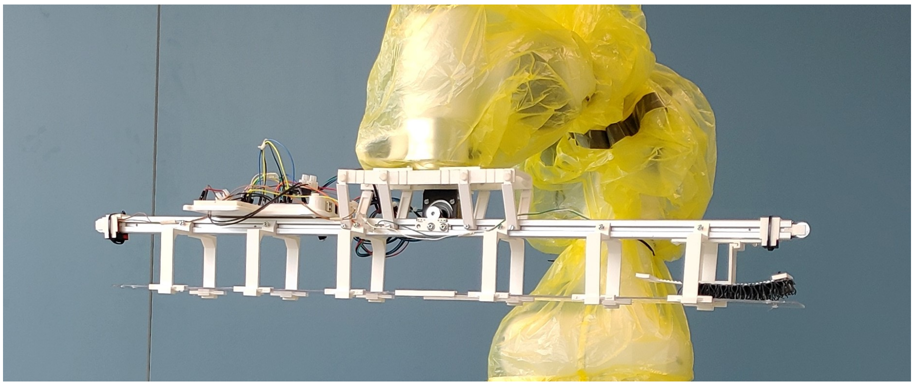


Figure 7.1: Carrier in normal(180degrees) position

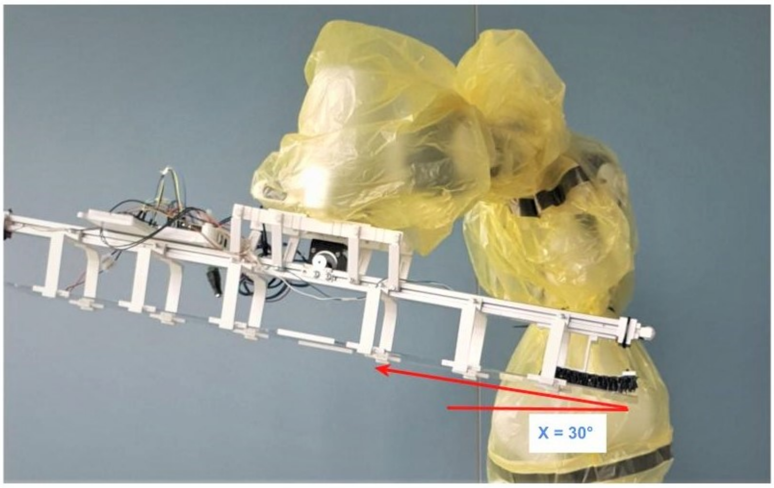


Figure 7.2: At an angle of inclination(30degrees) position

Figure 7.3: Carrier at an angle of inclination(60degrees)

Instruments

Various factors affecting the smooth transmission of instruments are tested using distinct sets of instruments. These instrument sets are categorized into three groups: picked, unpicked, and time-consuming, based on their grasping, sliding, and sensor recognition capabilities. Each set of instruments undergoes more than 10 tests with different combinations, and the results are presented in the tables below.

Picked Instruments

Figure 7.4: set of Picked Instruments

s.no	Instrument name	180°	30°	60°
1	Needle holder small	4.61000	4.62322	4.65033
2	Surgical scissors	4.61000	4.72240	4.84206
3	Probe with eye	4.60900	4.61020	4.61400
4	Needle holder large	4.61000	4.61345	4.61567
5	Sponge forceps	4.61700	4.62067	4.62377
6	Tissue holder small	4.60700	4.62845	4.63233

Table 7.1: Average Duration(in seconds) for Different Carrier Positions

Picked-but-Time-consuming

The "$Curved - Mayo - scissors$" is an instrument with a complex shape that creates challenges for the carrier to transmit it smoothly across a flat surface, ultimately leading to increased time consumption compared to other picked instruments.

Figure 7.5: Curved Mayo Scissors

Position(angle in degrees)	Avg.Duration(seconds)
180	7.85033
30	8.22056
60	8.84533

Table 7.2: Picked-but-Time-consuming

Unpicked Instruments

The various shapes and sizes of these instruments present a significant challenge when it comes to grabbing and transporting them using the carrier. This often leads to cases where the instruments are not picked up, resulting in them being included in the list of unpicked instruments.

Figure 7.6: Unpicked Instruments

7.2 Working efficiency of the speech recognition system

The offline speech recognition system's performance is evaluated by uttering the list of instrument names(30 instrument names in a different order 20 times each) into the microphone at various distances (ranging from 10cm to 1 meter) and in both quiet and noisy environments. The system exhibits improved accuracy in identifying instrument names when the ambient noise is minimized and the distance from the microphone falls within a moderate range. Additionally, there is ambiguity in the recognition of certain instrument names, with accurate identification occurring only when they closely resemble other instrument names in the vocabulary. For example, when dealing with instrument names such as "$Arterail - forces - curved$" and "$Arterail - forces - straight$," clear and complete pronunciation is crucial for successful recognition. The list of 15 instruments(due to space complexity) results are shown below

S.No	Instrument	Recognized Count
1	Army Retractor	20
2	Mayo Scissors	20
3	Arterial Forceps Curved	15
4	Arterial Forceps Straight	15
5	Dissection Forceps	18
6	Mosquito Forceps	20
7	Peritoneum forceps	20
8	Babcock Forceps	20
9	Stitch scissors	16
10	Needle holder large	20
11	Needle holder small	20
12	Probe with eye	19
13	Sponge forceps	20
14	Scalpel handle large	20
15	Scalpel handle small	20

Table 7.3: Working efficiency of the speech recognition system

7.3 Materials Cost

The following tables provide insights into the quantity of 3D-printed parts, the corresponding material usage, and the associated cost for both the instrument carrier and the instrument tray along with the other miscellaneous costs. This information can be helpful for evaluating the production requirements, material consumption, and financial implications of utilizing 3D-printed parts.

1. **3d-printed parts**

Metrics	Instrument Carrier	Instruments Tray
Total 3d-Printed parts	58	42
Material used (in grams)	458.81	216.44
Cost (Euro)	16.65	7.86

Table 7.4: Material (weight) and cost of 3D-printed parts

2. **Other Miscellaneous costs**

S.NO	Part	Quantity	Cost(Euro)
1	Stepper Motor	1	14
2	Pulleys	3	3
3	Timing belt	1	9
4	Plastic Mat	1	5
5	PC-glass plate	1	3
3	Infrared sensor	1	3
		Total	37

Table 7.5: Other miscellaneous parts and cost

7.4 Summary

This study provides insights into the instrument carrier system, instrument tray, speech recognition system efficiency, and material cost considerations. The analysis reveals the influence of carrier orientation on instrument transmission time and highlights challenges in instrument grasping and recognition. Improved speech recognition accuracy is observed in minimized noise environments. The study also provides information on 3D-printed parts quantity, material usage, and associated costs. These findings inform future improvements in instrument transport and organization.

This chapter presents the results of a thesis project that focuses on the instrument carrier system and the efficiency of the speech recognition system. The time taken by the instrument carrier to transmit instruments at different positions is analyzed, and the performance of the speech recognition system is evaluated under various conditions. Additionally, the material cost of 3D-printed parts and other miscellaneous costs are discussed.

8 Conclusion and Future Work

8.1 Conclusion

In conclusion, this thesis work presents a comprehensive solution for enhancing instrument handover in the operation theatre. By addressing the limitations of the traditional handover process, a novel instrument carrier system, instrument tray, and speech recognition module have been designed, evaluated, and optimized. The research questions of this thesis work are answered below with valid results and explanations.

1. **How can a simple instrument carrier system and an instrument tray setup with single-usage 3D-printed parts be designed?**

   The thesis work addresses this question by designing an instrument carrier system and an instrument tray using 3D-printed parts. The use of 3D-printed parts ensures simplicity and cost-effectiveness in the design, allowing for easy production and customization of the components.

2. **How to minimize the duration taken by the conventional gripper to hand over the instrument to less than 6 seconds by ensuring the patient and surgeon's safety?**

   The thesis work successfully tackles this question by replacing the conventional gripper with the new design of the instrument carrier system. The new system, incorporating 3D-printed parts, enables faster and more efficient instrument handover, reducing the transfer time which is observed between 4.6 seconds to 5 seconds(which is less than six seconds). The focus on patient and surgeon safety ensures that the optimized handover process does not compromise their well-being.

3. **How can the collaborative robot take input commands from the surgeon?**

   The thesis work addresses this question by developing and integrating a speech recognition module. The module allows the collaborative robot to receive input commands directly from the surgeon, enhancing communication and coordination during the instrument handover process. By accurately recognizing instrument names and understanding commands, the collaborative robot can effectively respond to the surgeon's instructions.

Overall, this thesis work contributes to the advancement of instrument handover processes in the operation theatre. The utilization of 3D-printed parts ensures cost-effectiveness, while the integrated speech recognition module enhances accuracy and productivity. By optimizing efficiency, safety, and communication, this research has the potential to positively impact surgical outcomes and improve patient care in the healthcare domain.

8.2 Future Work

While this thesis work has made significant progress in improving instrument handover in the operation theatre, there are several areas that can be explored in future research. The following aspects can be prioritized for further development and investigation:

Implementation of computer vision methods: Future work should focus on integrating computer vision techniques to enhance instrument recognition. By utilizing image processing algorithms and machine learning models, the system can accurately identify and classify different instruments, further optimizing the handover process.

Development of strategies for instrument retrieval: Investigating strategies and algorithms for retrieving instruments from the surgeon's hand can significantly enhance the efficiency and coordination of the handover process. Future research can explore techniques such as gesture recognition, motion tracking, or robotic manipulation to facilitate seamless instrument retrieval.

Integration of advanced technologies: The thesis work has laid the foundation for utilizing speech recognition for input commands from the surgeon. Expanding on this, future research can explore the integration of other advanced technologies, such as natural language processing, to enable more intuitive and interactive communication between the surgical team and the instrument carrier system.

Optimization of safety measures: Continuous improvement in safety measures is essential for the successful implementation of the instrument handover system. Future work should focus on refining safety protocols, developing fail-safe mechanisms, and conducting rigorous risk assessments to ensure the highest level of patient and surgeon safety throughout the handover process.

User experience and ergonomic considerations: To further enhance the usability and acceptance of the instrument handover system, future research can investigate user experience factors and ergonomic design principles. This includes studying the interaction between the surgical team and the system, optimizing user interfaces, and considering the physical comfort and efficiency of the users during the handover process.

By addressing these future research directions, the instrument handover system can continue to evolve and improve, ultimately leading to more efficient, accurate, and safe instrument transfers in the operation theatre.

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Declaration of Academic Integrity

I hereby confirm that I am the sole author of this work and did not utilize any external sources except for those that are cited or mentioned.

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