Contents

Introduction & Expected Outcomes

Interventions in the lumbar spine region require high precision due to the surrounding vital structures. Current common surgical tools in minimally invasive spine surgery (MIS) are rigid and are unable to provide adequate access the intervertebral disc without disrupting delicate structures such as the spinal cord. It is necessary to transition from rigid tools to an approach more capable of accessing and operating within this difficult space. A snake-like robot provides better access and manoeuvrability through increased degrees of freedom (DOF). As such, this project aims to answer:

Can a snake-like minimally invasive surgery (MIS) robot be optimised to enable lumbar spine surgical interventions?

The main objective of the project is to propose a method to design and construct a snake-like robot suitable for the requirements of lumbar spine surgery, with proof of concept demonstrated in the context of a lumbar fusion procedure.

The primary project deliverable is an algorithm that designs a snake-like robot for the purpose of lumbar spine surgery. The algorithm shall optimise the robot design to perform surgical tasks within a specified task space by considering the lumbar spine anatomy and operation constraints. The designed robot will be capable of accessing the interface between the intervertebral disc and vertebrae (bone) without disrupting surrounding structures as per lumbar spine fusion procedure requirements. A secondary deliverable is a built prototype of the snake-like robot.
A key objective is to define the sensitivity of the design outputs to the design inputs. This is important in working towards a generic solution that may work for the general lumbar spine case and be applicable to a large number of patients; in line with engineering sustainability practices.

To achieve the proposed deliverables, an engineering design process (cycle) has been implemented. This systematic approach involves:

1. Defining the requirements of the lumbar spine procedure and instrumentation.
2. Examining current approaches and their applicability to the lumbar spine case.
3. Examining the restrictions, limitations, and assumptions inherent to the current approaches, in the context of the requirements.
4. Defining a pathway to translate these approaches to be applicable for lumbar spine MIS.
5. Implementing modifications and refinements to develop a solution.
6. Evaluating the proposed solution through simulation, prototyping and testing.
7. Reiteration and further refinement of solution; cycle back to point 2.

Points 1-4 are addressed in semester 1 research; points 5-7 are to be addressed in semester 2. To answer the research question, first semester progress aims to answer the following basis questions:

a. What are the existing MIS approaches for lumbar spine surgery (specifically lumbar fusion)?
b. What are the existing snake-like MIS robotic approaches and can they be applied to lumbar spine surgery? i.e. can current approaches be applied to solve the research problem.
c. What are the main restrictions and assumptions that must be overcome to develop these technologies to be applicable to lumbar spine surgery?

Deliverables and Research Achievements

Deliverables

As outlined in the project proposal, the deliverables, and milestones for the first semester of the research project include:

- A project proposal and literature review.
- Answers to research questions (a) and (b). And (c).
    - Although question (c) is defined as a milestone of semester 2, the initial investigation which set up future practical applications were carried out in this first semester of work.
- The presentation of initial research findings in this progress report and an oral presentation.

These milestones are detailed in the Project Proposal *Timeline and deliverables* (Appendix A). The project proposal detailed the scope of work for this project. This alongside a literature review informed the basis for subsequent research.

Initial Research

Through the initial literature review it was found that limited research has been conducted on the application of snake-like robotics for the lumbar spine. Lumbar spine surgery requires high accuracy and precision. It involves working near vital and delicate anatomical structures and no snake-like technology has achieved the performance requirements necessary for clinical deployment (Santos et al, 2018).

The small workspace of the lumbar spine region imposes restrictions on aspects of the robot design including size and actuation. Snake robots achieve manoeuvrability through additional or redundant DOFs. A robot could be made to feature many segments with more DOFs to increase flexibility. However, it is important to consider the actuation of these segments. For example, a tendon driven robot requires additional tendon channels for every additional segment. At the small size required for MIS this may compromise the structural integrity of the robot. As such, the configuration of segments and DOFs must be carefully defined to minimise the actuation requirements.

Due to the restrictions of designing a robot for a specific environment, a key design approach is an optimisation algorithm. These work to optimise design parameters to achieve high capabilities, for example dextrous abilities. One of these algorithms is the SnakeRaven design algorithm which was developed surrounding a study of knee arthroscopy. This algorithm focuses on the optimisation of snake robots for specific tasks and task spaces in knee surgery (Razjigaev, 2022).

The SnakeRaven design algorithm involves analysing a 3D scan of knee anatomy and defining targets and obstacles. Then by calculation of the forward kinematics of a roller-joint robotic system (See Figure 1), the tool's dexterity and workspace can be determined; these are the metrics used for optimisation. The designs produced by the SnakeRaven design algorithm achieved greater dexterity than state of the art rigid tools. However, the implementation of such algorithms to the lumbar spine case had not yet been investigated. Additionally, from early research, limitations due to assumptions in the surgical procedure including incision port and other anatomical characteristics of the workspace in a real surgery, could be identified.

Further research is conducted to answer research questions (a) (b) and (c) which were developed to comprehensively understand the limitations of current approaches and the course to overcome them.

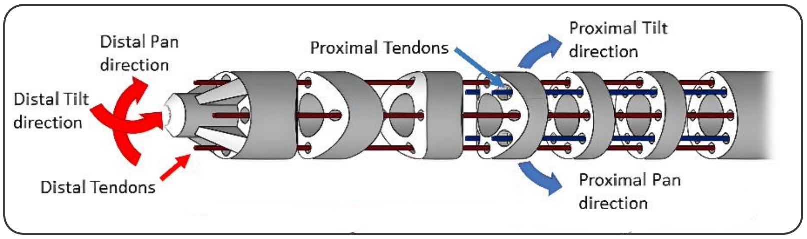


Figure 1 - Rolling joint tendon driven robot design (Razjigaev, 2022)

Existing MIS approaches for lumbar spine surgery

By investigating current MIS approaches for the lumbar spine, the requirements and constraints for surgical tools can be defined.

The aim of lumbar interbody fusion surgery is to implant a spacer between two vertebrae that promotes bone healing to fuse the two vertebrae (Santos et al, 2018) (Refer to Figure 2). During LIF the surgeon removes the weakened intervertebral disc; this is referred to as a lumbar discectomy. This space can be accessed by removing the lamina (Posterior LIF, PLIF) or through creating bone openings (Transforaminal LIF, TLIF). It is key to protect neural structures during this manipulation (Jitpakdee et al, 2023). Current MIS operations are slowed by the discectomy which is typically the longest part of the procedure and vital as fusion depends on the proper preparation of the disc space (Qureshi, 2020). The risks associated with this procedure include non-union or a failed fusion and nerve damage (Armaghani, 2020).

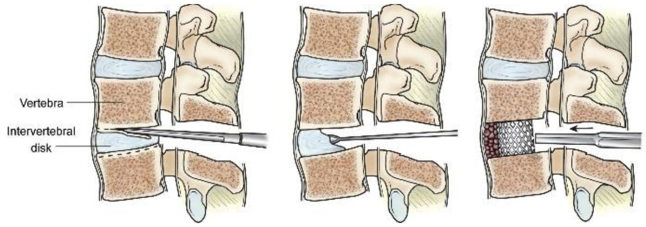


Figure 2 - Discectomy and spacer insertion for lumbar fusion procedure (Pillay, n.d.)

The incision required for MIS TLIF is 2-3cm through which dilators are used to expand a surgical corridor and a tubular non-expandable retractor is inserted; this process allows the thecal sac, which contains the spinal cord, to be repositioned out of the way. Thus, instruments are constrained to the physical bounds of the retractor passage. For a lumbar discectomy a space of 15 to 20 mm in diameter is needed and so retractors are commonly 20mm (approximately between 15 and 23mm) and a length of 40 to 50 mm (Kim et al, 2007) (Phillips et al, 2019). Commonly used thin-walled retractors are 0.9mm in wall thickness. Instruments are restricted by this space and are typically less than 5mm in diameter. Examples of instruments are Adson hooks (5mm), and Kerrison punches (2-5mm) (Mercian, 2023) (Figure2 (a) & (b)).

This current instrumentation for lumbar spine MIS is restricted by lack of tool tip dexterity. For example, endoscopes are commonly constrained to set viewing angles refer to Figure 2 (c) (Goldberg, 2024). Similarly, microsurgical tools such as pituitary rongeurs (Figure 2 (d)) have limited manoeuvrability inhibiting access to occluded regions of the lumbar spine. This poses a challenge for surgeons who require access to the entire intervertebral disc space for fusion preparation.

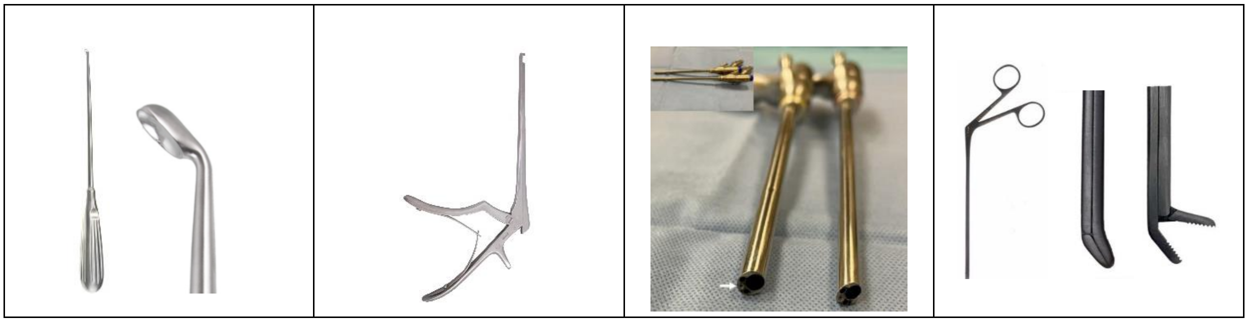


Figure 2 - Spine MIS tools. (a) 5mm Adson hook. (b) Kerrison punch. (c) Interlaminar and transforaminal surgery endoscope with 15° (left) and 30° (right) camera angles. (d) Micro Pituitary Rongeur. (Mercian, 2023), (Goldberg, 2024).

Defining requirements and the task space

After identifying the requirements of lumbar spine interventions and current methods, the design objective for the snake-like robot can be further refined to be an instrument capable of reaching the space of the intervertebral disc with the following constraints:

- The tool should be capable of reaching all points within disc space from a 20mm entrance port.
- The port additionally constrains movement through the stiff tubular structure of the retractor, which is 40mm in length, 20 mm in diameter and has walls of 0.9mm thickness.

We can visualise the task space as per Figure 3.

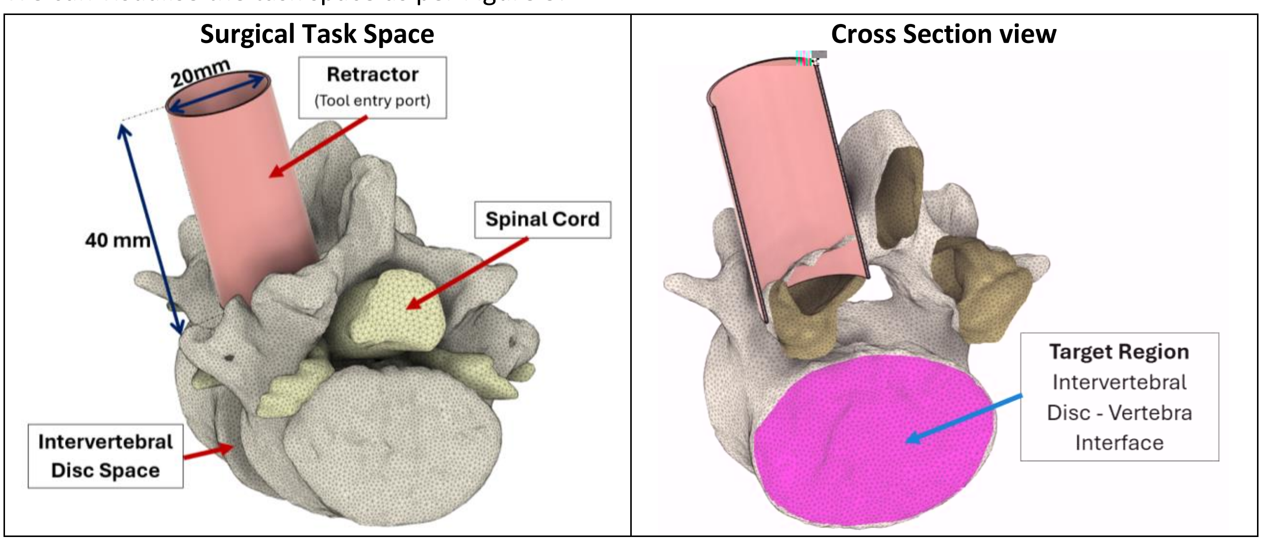


Figure 3 - Task space visualisation (Retractor at 20° incline from vertical axis). Note: Opposite vertebra surface is also included as a target region.

Existing snake-like MIS robotic approaches and potential applications to lumbar spine surgery.

Clinical applications of snake-like robots are not yet widespread, and the scope report literature review discovered no approaches have been applied to the case of the lumbar spine.

The SnakeRaven design algorithm (SRDA) was selected as the platform from which potential lumbar spine surgery applications could be developed. This algorithm is coded on MATLAB. To determine the suitability of this design algorithm to the case of the lumbar spine the design algorithm was investigated in its original application to knee anatomy as well as implemented on a spine segment. Through this testing it was possible to identify the assumptions and limitations of the algorithm.

The SRDA can be broken into two main components; each contained within its own MATLAB script. i) The computerised mapping of the surgical workspace through voxelisation and ii) the evolutionary optimisation of snake robot design to the constraints of the voxel model.

i. Task Space Voxelization: Mapping the surgical task space.

Given a 3D patient anatomy scan, the SRDA requires the segmentation of the task space into voxels to define the task space, objectives, and obstacles. In reviewing the application of the SRDA to the knee anatomy some key differences/constraints were identified.

The knee arthroscopy surgery task for which the SRDA was designed uses a task-based approach which optimises the robot design to reach specific targets in a patient specific task space (Figure 4).

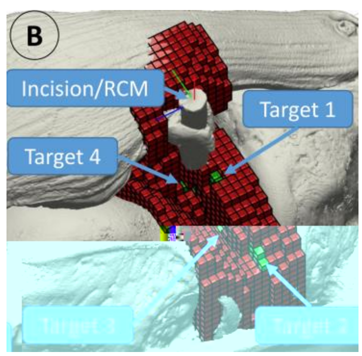


Figure 4 - SDRA voxelisation applied to knee model for task specific optimisation (Anatomy voxels in red and targets in green) (Razjigaev, 2022).

The task space for lumbar spine is more correctly defined as a target surface; not a set of separate points as SRDA implementation. A lumbar spine 3D CAD model was used to apply the SRDA. A target area is defined as the surface of the vertebrae on which the intervertebral disc is located.

The spine geometry was extracted to define and voxelise the region of interest (Figure 5). Being a far greater surface, the voxelisation process is far more computationally intensive, slow and inefficient. To improve speed, a thin sliver of the model was used; this captured the surface characteristics of the model but minimised the number of voxels required. Additionally, due to computational limitations, the size of the voxels was increased by 400%. This, however, left the model to be more jagged and a less accurate representation of the true smooth surface.

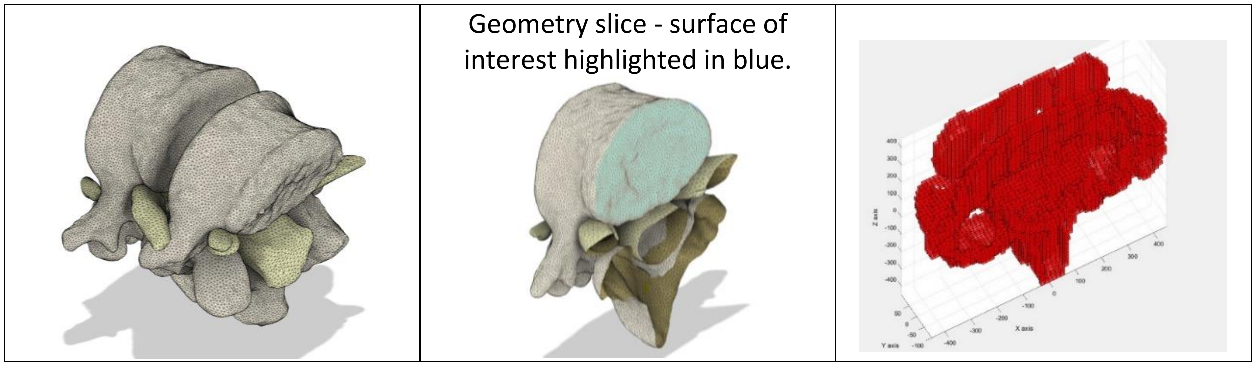


Figure 5 - Extracted lumbar spine geometry, region of interest and voxelised model.

Even at the lower resolution the voxelised model was too large to compute through the SRDA. Hence, a smaller task space was defined and within this area a small voxel cluster was defined as the target point (Figures 6 and 7). Figure 6 shows this target region defined within the greater lumbar spine model. The entry point of the tool was also defined to a set the point, the remote centre of motion, where the tool will extend from. This placement is in line with defined task space.

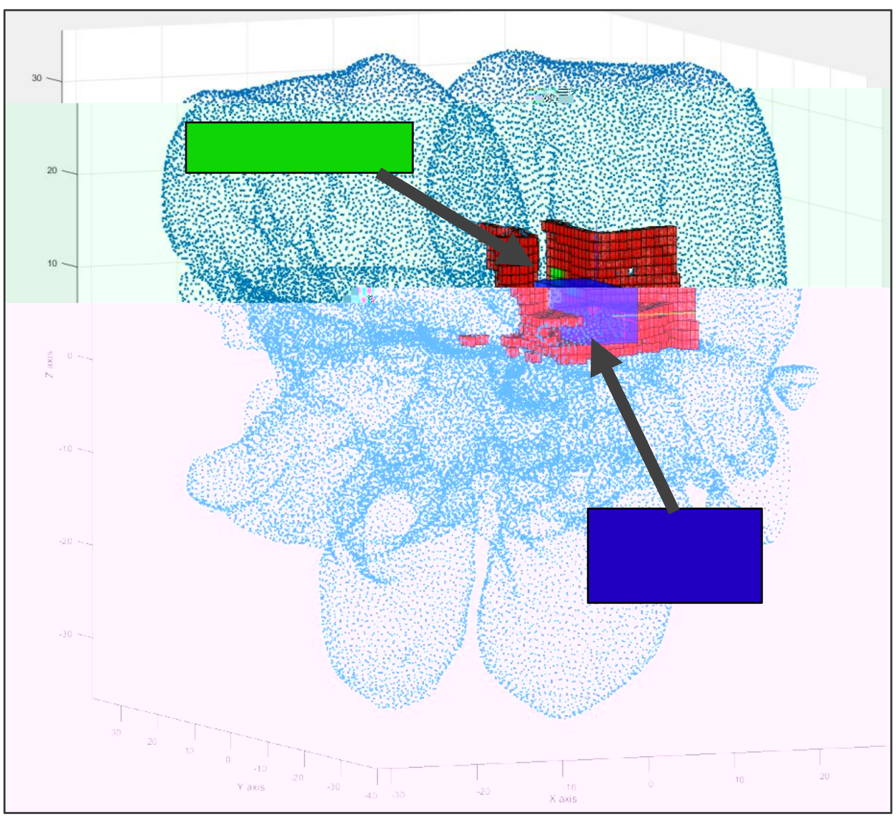


Figure 6 - Smaller task space voxelised (red) within larger model (blue).

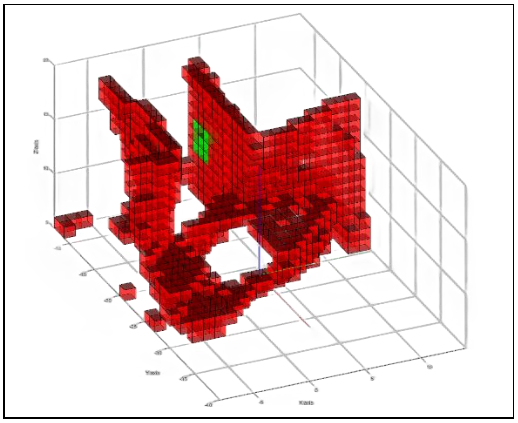


Figure 7 - Target point (green) within voxelised task space (red).

ii. Optimisation of a roller joint snake robot design.

The voxel model was then inputted into the optimisation script of the SRDA. The SRDA uses workspace reachability and dexterity measures as the metrics to optimise in a design.

ii.1 Dexterity and Workspace Reachability

The reachable workspace refers to the regions the robot has ability to reach. For each robot design it is found through statistical observation of the robot's configurations and their ability to reach the target workspace. The reachable workspace is determined by the forward kinematics of a robot design and can be computationally calculated through sampling methods, namely the Monte Carlo method.

Dexterity measures the instrument's capacity to approach a voxel from different orientations. It is defined as a percentage relating the capacity to approach a voxel (or point) from some orientations to the total possible orientations. The SRDA uses a service sphere model to illustrate the dexterity at each point in space. Each voxel can be represented by a service sphere. The surface of the sphere represents all the possible orientations of the voxel. Then the service region can be defined as all the orientations achievable by the end effector (snake robot).

ii.2 Evolutionary Optimisation of Design Parameters

The SRDA employs an evolutionary algorithm to solve for design parameters which define the structure of a rolling joint snake robot. These parameters describe: the width of the robot (w, diameter), the number of rolling joints (n), the distance between each rolling surface (d) and the half angle of curvature for the rolling joint (alpha). The width of the robot was set to 4mm which is within the surgical instrument requirements of MIS. This is the only parameter which is manually set. These parameters are stored in a vector referred to as the parameter vector and describe one robot configuration.

The algorithm optimises a fitness function that assesses each robot configuration's dexterity and workspace reachability measures. The differential evolution algorithm first creates a population of randomly generated parameter vectors and measures the fitness of each resulting design. Then it combines a set of these population members using mutation and crossover techniques to create a trial vector. The fitness of this trial vector is computed and is compared to a vector within the population. The new vector will take the place of the old vector if it achieves a greater fitness score.

The SRDA was tested using a population size of 30 and allowing for 100 generations of iterations of optimisation. This resulted in the testing of approximately 1500 unique designs in order to converge to the optimised design parameter configuration. This computational effort requires parallel computing.

ii.3 SRDA Optimisation: Lumbar spine case

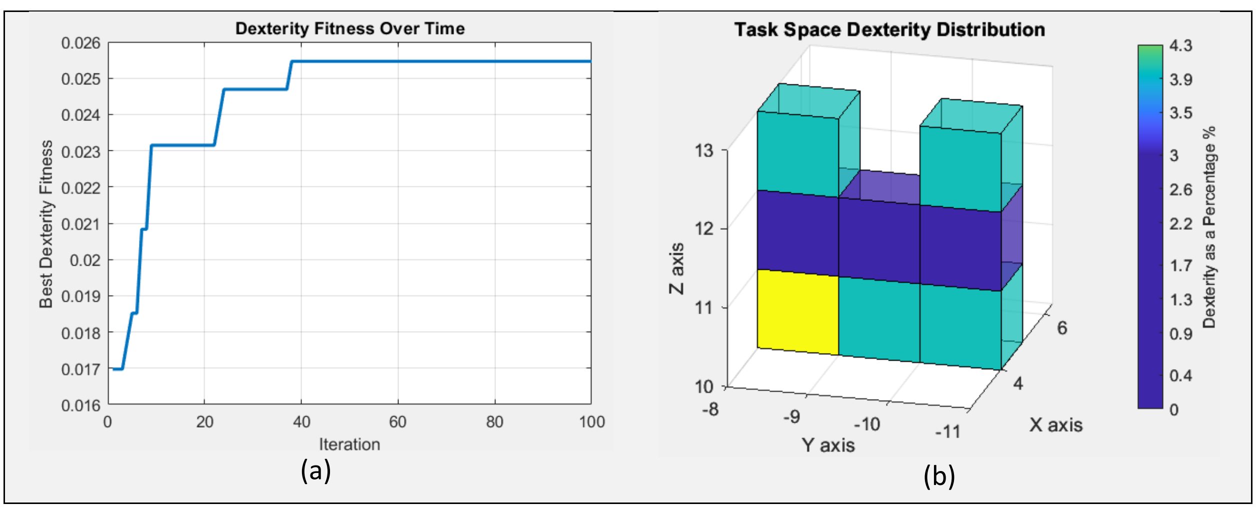
The voxelised lumbar spine model was processed through the optimisation algorithm. The SRDA produced the following outputs and graphical visualisations of the results.

Fitness Over Time (Figure 8 (a)) – The design fitness of each evolution iteration (generation) is plotted over the total generations. This shows how the algorithm progressively works to improve the robot's fitness (dexterity) score. It can be observed that around generation 40 the fitness score plateaus at 2.55%. In the context of the SRDA's original implementation this is considered a low score.

Voxel Dexterity Distribution (Figure 8 (b)) **–** This graph uses a colour scale to display the distribution of dexterity among the target voxels. The dexterity score describes the robot's ability to reach each of the voxels that make up the target point. From this graph we can see that dexterity ranges from 0% to 4.3% with a majority of the perimeter voxels achieving a higher dexterity score.

Visualisation of the maximum dexterity achieved (Figure 8 (c)) **–** This graph visually represents the maximum dexterity achieved for a target voxel. The score suggests that the voxel could be approached from 4.3% of the total orientations distributed as per the sphere's surface.

Render of Snake Robot Design (Figure 8 (d)) **–** The MATLAB program also creates a render of the snake robot design. The 3-segment design features 2 rolling joints with a half angle of curvature of 1.5 radians. It measures 4mm in diameter and approximately 14mm in length. These MATLAB optimised parameter outputs are captured in Figure 9.



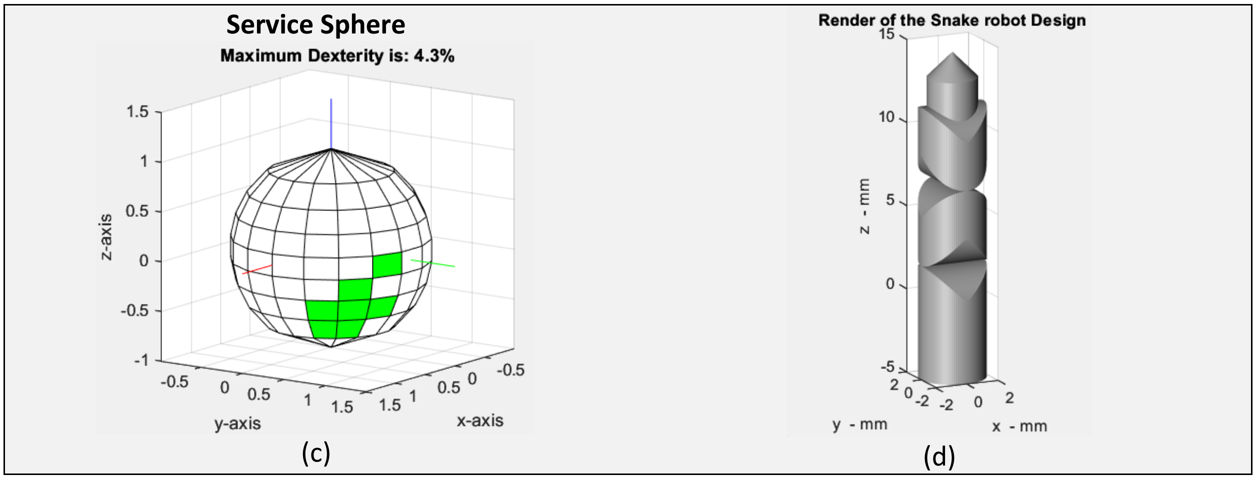


Figure 8 - SRDA MATLAB Outcome Visualisations

```
Evolution Results. The Best solution was:
    alpha: 1.5000
        n: 2
        d: 1.0300
        w: 4

With best Dexterity:
    0.0255
```

Figure 9 - Optimisation script: MATLAB output.

Through applying the SnakeRaven code to the lumbar model we can begin to identify the limitations of the algorithm. And this then informs the proposed modifications to improve the algorithm.

Restrictions and assumptions that must be overcome to develop these technologies to be applicable to lumbar spine surgery.

The final research question sets up the second stage of this research project, which is concerned with modifying the current design method, SRDA, to be applicable to the lumbar spine case. Outcomes from this stage will inform the proposed modifications.

The limitations and assumptions required to be overcome in order to design a snake-like robot for lumbar spine intervention include:

Task Specific approach – The current algorithm is restricted in its application to the lumbar spine anatomy through its task-based approach. A discectomy requires access to entire surfaces as opposed to small point targets. The SRDA is not adapted for working with these large regions of interest.

Model voxelisation – The voxelisation approach introduces several drawbacks when applied to the lumbar spine case. The discrete method is computationally complex and requires processing of large amounts of data especially for larger anatomical models. This results in inefficient use of computational resources and long processing times when running the SRDA. These drawbacks further constrain the algorithm's scalability to real-world clinical applications.

Voxelised models also limit model resolution. This restricts application to the lumbar spine procedure such as discectomy which requires good representation of anatomical structures. These inaccuracies can impact validity of the optimisation process.

Optimisation metrics – To access the intervertebral disc space and perform tasks such as discectomy, it is necessary to access every surface point thus workspace reachability is a key measure. However, it is not required in practical application that every point be reached from all possible orientations (dexterity). The SRDA works on the assumption that dexterity maximisation produces the optimal instrument. This approach limits the algorithm in eliminating potentially viable robot designs due to this high but unjustified requirement.

A more realistic dexterity requirement is estimated by considering the purpose of the snake robot and characteristics of a point on the target surface (e.g. on the bone). Figure 10 illustrates this concept where the surface of the sphere represents the possible orientations from which a robot may approach the point. The target point cannot be reached from orientations within the bone which eliminates 50% of the possible orientations. For probe or ablation applications (used in discectomies) the robot only needs access from one side of the point (does not need to wrap around the point); this eliminates another 25% of the orientations. Beyond this, it is unlikely that all orientations, particularly at the border, will require access which further halves the requirement. Therefore, in a realistic application approximately 12.5% to 25% of orientations (or dexterity) are required for optimal results.

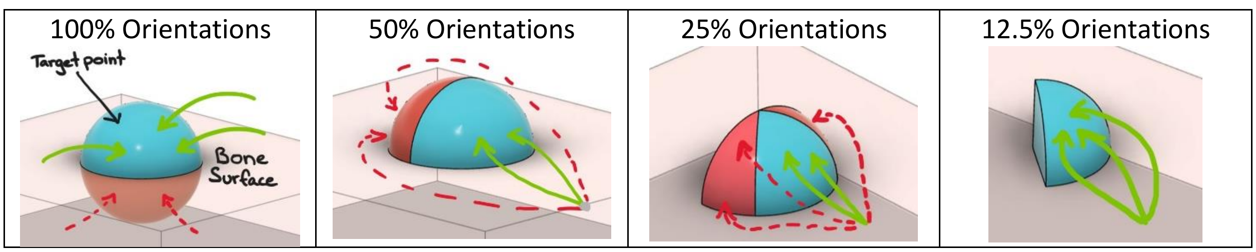


Figure 10 - Dexterity Requirement Concept Diagram (Red dotted arrows show unnecessary or impossible tool approach orientations, green arrows show possible or required tool approach orientations)

Tool entry port characteristics – The SRDA works under the assumption that the surgery incision port is flexible, and the robot can approach the surgical site from various orientations. This is not applicable to the case of the lumbar spine surgery procedure due to the fixed and stiff retractor entry passage which limits the angles from which the robot can approach the target area (Refer to Figure 11).

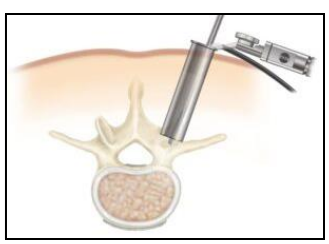


Figure 11 - Entry is restricted by stiff retractor.

The Modified Approach

The modified approach is a continuation of research question (c) and a semester 2 deliverable, however, a preliminary outline of how the problem will be approached has been developed in this semester. Each modification responds to a limitation identified in section (c). These refinements to the current SnakeRaven design algorithm aim to improve its applicability to the lumbar spine case.

Volume based approach to replace the task-specific framework.
For the case of the lumbar spine, we require a volume-based approach that optimises the robotic tool considering its ability to reach an entire surgical workspace.

This approach also introduces opportunity to develop a robot that works for the general lumbar spine anatomy avoiding the complexities of introducing patient specific instruments in clinical settings. This is particularly relevant to the sustainability considerations further explained in the *Ethics & Sustainability* section of this report.

Continuous methods for mapping a surface to replace the discrete voxelisation method.
Mapping the large lumbar spine target region requires transitioning to an approach more capable of handling high resolution datasets. A continuous method allows us to approach the problem from an analytical perspective, leveraging mathematical functions to precisely map the surface topology. This continuous function approach will also improve the efficiency of computations (algorithm execution) in avoiding the need to process high resolution discrete voxelised models when optimising.

Gaussian process methods are the chosen approach. A gaussian process method allows us to interpolate between data points which allows for a more comprehensive representation of the lumbar spine model. This allows for flexibility in the selection of the resolution (of the model) considered in the optimisation algorithm; that is, we can choose the number of surface points at which to evaluate the designed robot's capabilities.

Redefining the optimisation metrics to replace current high dexterity requirements.
An algorithm more suited for the large target regions of lumbar spine interventions will prioritise workspace reachability over point dexterity.

Additionally, the dexterity requirements will be further reduced by defining specific required orientation (angle) ranges. The current framework maps the possible orientations (service sphere) considering all angles to each target point. A modified approach will (initially) reduce this to only consider 12.5% of the orientations as per Figure 10 concept. That is, the current 12.5% region will be considered the total possible orientations i.e. 100% of the service sphere surface.

Definition of Entry Port to enforce real world MIS constraints.
The entry port characteristics for lumbar spine MIS must be considered. This will involve correctly positioning the start point of the robot when modelling the workspace; this is defined by the Remote Centre of Motion (RCM) variable in MATLAB. The retractor, which restricts the robot's approach, can also

The following table summarises the identified risks, consequences, and mitigation strategies. The risk classification is determined by the consequence severity and likelihood matrix (Appendix B). Additional, currently unencountered but possible future risks have also been included.

Table 1 - Project Risk Summary

Risk	Consequence (Severity, Likelihood)	Risk category	Mitigation
Scope Creep Risk for project scope to expand beyond capability.	Overload of milestones and tasks preventing progress toward overall project outcomes. **(Major, Possible)**	High	Careful definition of research question and scope. Continual referral to project proposal guidelines.
High computational requirements	Time wasted in running intensive algorithm and inefficiency. **(Major, Likely)**	High	Improving code efficiency and acquiring access to more powerful computing resources.
Unable to use MRI lumbar spine model	Unable to test algorithm and halt to project process. **(Major, Minor->Likely)**	High	Use more general CAD models available online. (This risk has been controlled).
Extended project timeline due to setbacks.	Prevents successful completion of project. **(Moderate, Possible)**	Moderate	Good project management through task tracking, regular revision of project plan and proactive action to correct setbacks.
Lost algorithm code or alterations to code beyond repair.	Lack of code traceability or loss of code. This impacts productivity in having to redo tasks. **(Major, Possible)**	High	Code management will be implemented through use of GitHub software for version control.
No access to necessary resources e.g. Raven II	May delay or terminate project progress. **(Major, possible)**	High	Access to resources will be organised far in advance. Alternative simulation testing methods are planned to avoid dependency.
Lab Hazards during testing – including damage to equipment and safety hazards.	Testing equipment maybe behave unexpectedly causing collisions during testing. **(Minor, Possible)**	Low	Conducting risk assessments before testing and correct use of test equipment: Consulting product instructions, guidelines, experienced user, lab protocols and wearing PPE.

Ethics & Sustainability

Ethics

In decision making and conduct, it is a priority to stay in aligned with the *Engineers Australia Code of Ethics and Guidelines on Professional Conduct* (EA-CEGPC).

I uphold professional integrity and transparency (EA-CEGPC Guidelines 1.1, 1.2) by always representing findings accurately and acknowledging the limitations of the project. This has been implemented in all project documentation (including project proposal document).

I have engaged responsibly with my stakeholders (EA-CEGPC Guidelines 4.1) through frequent project updates. I have ensured my supervisors are up to date and have submitted draft project documentation so they could provide feedback, contributing to the refinement of my project's development. This also better ensures the alignment of my project with stakeholder expectations.

Clear communication of potential risks and limitations of my project has been consistent. Additionally, I have adhered to a well-structured engineering design process to ensure I can act on the basis of adequate knowledge (EA-CEGPC Guideline 2.2). Following these guidelines has been essential in the development of ethical research with intended medical applications.

Sustainability

Sustainability is also a key focus. Following the guide of *the Engineers Australia Implementing Sustainability: principles and practice guidelines*, (EA-ISppg), this project aims to contribute to the development of environmentally conscious technologies within the clinical field.

This project follows these sustainability guidelines by considering the life-cycle and span of the snake-like robot (practice C6.1, Stewardship, Product end of life). The prevalence of waste in the clinical setting was made apparent during a hospital visit. I was invited to view two surgery procedures performed by stakeholder Dr. Ross Crawford. Plastic is a common material for disposable clinical tools. During the surgery viewings it was clear that plastic was utilised at all stages of surgery from the surgeons' garments to the surgical sutures. It is a common material used for instrument construction due to its low cost, flexibility, biocompatibility, and disposability.

Based on this observation it was decided that efforts should be made towards reducing the environmental impact of this project. Whilst previous approaches have focused on single use, patient-specific disposable instrument design, this project will explore volume-based solutions that are potentially multipurpose. The successful design of this standard device supports the case for reusable, sterilisable tools which avoid the resultant waste of single use tools.

The use of an optimisation algorithm also addresses sustainable practice C3.5 (Design. Process optimisation). This alongside efforts to create a multipurpose reusable robotic tool enables better use of materials fulfilling practice C3.4 (Design. Resource efficiency).

Resources

My research relied heavily on literature resources referenced throughout this report.

As my project aims to refine the SnakeRaven design algorithm, this is the code resource I worked with throughout the semester. Andrew Razjigaev the author of the SnakeRaven algorithm published this algorithm on GitHub. Other published (online) documentation includes his thesis, research papers and presentation and experiment videos. I have interacted with these resources to better understand the SnakeRaven design algorithm.

An overall project resource table (Appendix C) was developed for the project proposal document. This includes resources that have not yet been required but will be used in semester 2 for prototyping.

Stakeholders and other acknowledgments

My supervisors Prof. Cameron Brown and Prof. Will Browne supported the development of my project. Their expertise provided guidance which shaped the focus of my research. Through regular meetings and discourse I was able to refine my project scope, outcomes, design choices and the engineering design process employed to complete my project.

Prof. Cameron Brown guided me toward algorithm modification as a pathway to answer my research question and develop a solution. He plays a key role in ensuring my proposed refinements are technically sound and has provided much insight into the current technological opportunities and limitations relevant to my project objectives.

As an artificial cognitive systems expert, Prof. Will Browne guided me towards the gaussian process methods which will be implemented in the modified algorithm to improve the code efficiency and applicability for the lumbar spine case.

My project stakeholder Dr. Ross Crawford provided many insights into real surgery operations. Being invited to view two of his surgeries (in person) earlier in the semester, I witnessed first-hand the extensive use of plastic in surgical procedures. It was also evident sanitation and patient safety was the ultimate priority. This had a significant impact in setting a goal to align my project with environmental sustainability while maintaining patient safety and sanitation standards.

Conclusion

This research project aims to develop a method to design a snake-like robot that enables lumbar spine interventions. This will be achieved through adherence to engineering design process practices in the refinement of the current SnakeRaven design algorithm (SRDA). This report outlined the project progress, which includes: the identification of robotic instrumentation requirements for lumbar spine MIS, the current capabilities of the SnakeRaven design algorithm, its limitations, and the required improvements. This project has been enabled through stakeholder support and has considered engineering ethics and sustainability practices. Pertinent risks have been identified and mitigation strategies have been developed to ensure the success of the project. Despite some challenges a new approach to modify the SRDA has been proposed establishing a good foundation for the second semester of research.

Sign off.

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Spinal Instruments

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Spinal Fusion: Minimally Invasive, TLIF and PLIF

End-to-End Design of Bespoke, Dexterous Snake-Like Surgical Robots: A Case Study with the RAVEN II

Developing a Macro-Micro Teleoperation System with Snake Robots for Minimally Invasive Surgeries

Introducing SnakeRaven

DesignAlgorithm_SnakeRaven

The future of minimally invasive spine surgery in low-income Latin American countries.

Device solutions for a challenging spine surgery: minimally invasive transforaminal lumbar interbody fusion (MIS TLIF).

Minimally Invasive: Transforaminal Lumbar Interbody Fusion

The human spinal column

Lumbar microendoscopic discectomy: surgical technique and nuances.

Clinical applications of the tubular retractor on spinal disorders

Appendix

A: Project Proposal - Timeline & Deliverables (Semester 1)

Table - Timeline & Deliverables – Project Proposal (Green shaded sections are complete or in progress).

B: Consequence severity & Likelihood Matrix

Table - Consequence severity & Likelihood Matrix
