Design of Two Switch Mechanism Concepts for a Surgical Shears Device

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Abstract

Since the widespread introduction of laparoscopic cholecystectomy in late 1989, the minimally invasive surgery (MIS) has been under rapid development and had been applied to many classes of traditional surgeries. Minimally invasive surgery (MIS) challenges the surgeon's skills due to his separation from the operation area which can be reached with long instruments only. Along with the germination of the first surgical robot in 1985, it was not until April 1991 that the first robotically assisted MIS was clinically applied to patients in a minimally invasive prostate surgery. Safety, Precision, Reliability over multiple and long procedures and ease of use for physicians are the most vital factors in a surgery. Robotics and Automation facilitates above factors decreasing surgery time and recovery time of the patient. This paper addresses improved design of two switch mechanism concepts from existing handle mechanism increasing safety by locking jaw movements at open and close positions, ease of usability and assisting surgery automation i.e., performing the required assignment with just two switch movement & this proposal could come into practical existence when Computer Assisted Surgery (CAS) replaces manual methods. The Objective is to design a mechanism to evade partial holding and to seize accurately by locking the jaw movements. The paper presents different mechanism concepts for the function of two switches controlling jaw movements individually and locking the jaw movements at open and closed position. Paper also briefs the methodology used in concept development and concept selection according to specific criteria.

Keywords: Minimally invasive surgery, Laparoscopy, Safety, Automation, Concept development, Concept selection, Concept Scoring Matrix

1 Introduction and Motivation

Minimally invasive surgery (MIS) is an operation technique established in the 1980s. It differs from open surgery in that the surgeon works with long instruments through small incisions (typically smaller than 10 mm) and that he has no direct access to the operating field as in open surgery. The main advantages of MIS compared to open surgery are small incisions, which reduce pain and trauma, shorter hospital stays, shorter rehabilitation time, and cosmetic advantages. Only disadvantage is direct hand eye coordination as in open surgery is lost [1], as the long instruments (approx. 30 cm) have to be moved around an invariant point (entry point or fulcrum point) on the patient's body. Key technologies to overcome the drawbacks of manual MIS are robotics and automation, which help the surgeon to regain virtually, direct access to the operating field. Concepts were made with safety and ease of automation in mind with interlocking the jaws at open and closed.

1.1 Existing Surgical Instrument

Existing surgical Instrument (Fig. 1) basically consists of a tool assembly and a detachable handle. The tool assembly consists of an outer sleeve to which a surgical jaws assembly is mounted. An Inner Extension is mounted inside the sleeve and is longitudinally translatable with respect to the sleeve.

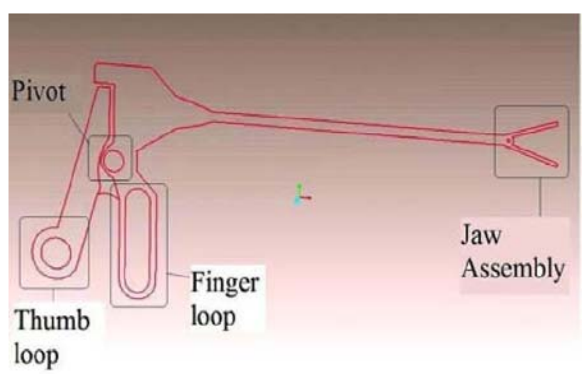

Fig. 1: Original device Sketch

When the distal end is in engagement with the jaws of the jaw assembly, translation of the extension will cause the jaws to open and close. Relative rotation between a thumb loop and finger loop on the handle assembly longitudinally translates the extension within the sleeves, and thus opens and closes the jaws. Surgical Instrument is basically used for handling tissues in laparoscopic & endoscopic surgeries and when connected to electrocautery source controls Homeostasis. It is also used with a non traumatic grasper simultaneously to dissect and expose the Gastro esophageal junction

2 Methodology

2.1 Five step method for Concept Generation

A five step concept generation process (Fig 2) has been followed breaking complex problem into simpler problems, Solution concepts are then identified for the subproblems by external and internal search procedures. Classification trees and concept combination tables are then used to systematically explore the space of solution concepts and to integrate the sub-problem solutions into a total solution

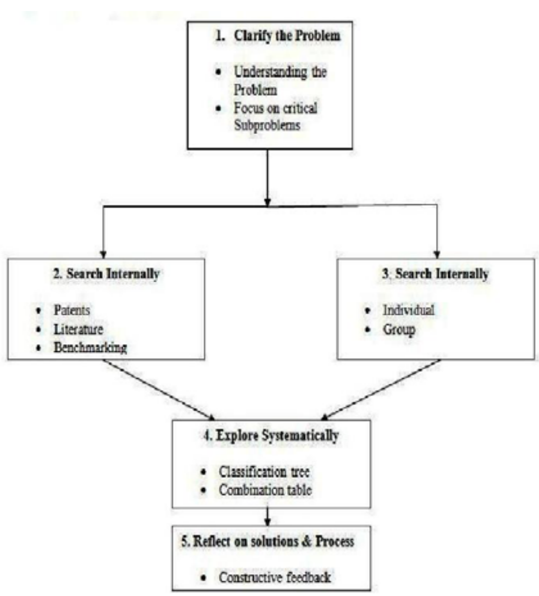

Fig. 2: Concept generation process

2.1.1 Step 1: Clarifying the Problem

Clarifying the Problem consists of developing a general understanding and the breaking the problem down into sub-problems if necessary. A Mission statement, list of requirements to be fulfilled is prepared with assumptions according to the prevailing conditions. Assumptions were Snap fit locks the jaw movement at open and closed positions & spring usage results in quick movement of the circular bar.

2.1.2 Step 2: Search Externally

Objective of the search is to expand the scope of search by broadly gathering information that might be related to the problem & then focus the scope of the search by exploring the promising directions in more detail. A detailed search [2,3,4,8] is made on existing patents, published literature as per the problem requirement. Consultation of Surgeons was performed for data on surgery methodology and usage of this particular instrument in the surgery to make the limitations list in making the concepts.

2.1.3 Search Internally

Internal search was the third step in the process where analogies have been made by questioning "what other devices solve a related problem and what devices do something similar in an unrelated area of application?" and beginning a thought "I wish we could ....", "I wish what would happen if ...." enhancing the scope of creativity.

2.1.4 Explore Systematically

Systematic exploration is aimed at navigating the space of possibilities by organizing and synthesizing these solution fragments. Concept Combination table is prepared for exploration. Combination table is simple a way to make forced associations among fragments in order to stimulate further creative thinking; in no way does the mere act of selecting a combination yield a complete solution. Combination table is prepared to put fragmental solutions for a novel solution with springs gears, linkages and Rack& pinion.

2.1.5 Step 5: Reflect on the results and the Process

Although the reflection step is placed at the end of convenience in presentation, reflection should in fact be performed throughout the whole process. Questions to ask include:
Is the solution space fully explored?
Are there alternative function diagrams?
Have external sources been thoroughly pursued?
A detailed analysis has been performed for the present problem, reworking has been done on the following questions to finalize the mechanism concepts.

2.2 Concept Selection

Concept scoring is used when increased resolution will better differentiate among competing concepts. A four step process is carried out for preparing the scoring matrix as follows:

2.2.1 Step 1: Prepare the Selection Criteria

The concepts which have been identified for analysis are entered on the top of the matrix. Use of hierarchical relations is a useful way to illuminate the criteria.

2.2.2 Step 2: Rate the Concepts

As in the screening stage, it is generally easiest for the team to focus its discussion by rating of the concepts with the respect to one criterion at a time.

2.2.3 Step 3: Rank the Concepts

Once the ratings are entered for each concept, weighted scores are calculated by multiplying the raw scores by the criteria weights. The total score for each concept is the sum of the weighted scores.

2.2.4 Step 4: Reflect on the results and the Process

As a final step the team reflects on the selected concepts and on the concept selection process. Review of strengths and weaknesses of the methodology in relation to the needs is performed.

3 Mechanism Concepts

3.1 Mechanism concept 1

The Circular bar is connected to the linkage with the help of a slot and cylinder mechanism. Snap locks the circular bar at open and close position. The linkage is pivoted around above the circular bar to facilitate the connected movement of forward and backward switch. This mechanism was prepared with mechanism advantage in mind.

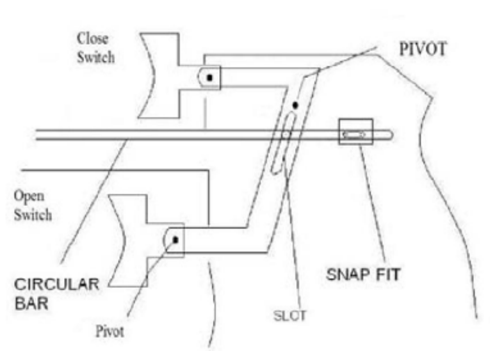

Fig. 3: Mechanism Concept 1

The merits of this advantage are its purely mechanical, having a mechanical advantage over the existing mechanism and interlocks the forceps at open and close positions.

3.2 Mechanism Concept 2

In this Concept, Open switch is connected to the circular bar with the help of linkage and rack and pinion mechanism. The number of tooth on the rack which converts the translation of the Switch to circular motion of the Pinion is responsible for a higher mechanical advantage over the existing Instrument. The close button is directly connected to the circular bar. Snap locks the circular bar at open and close position. An Exercise bike analogy was used to construct this mechanism.

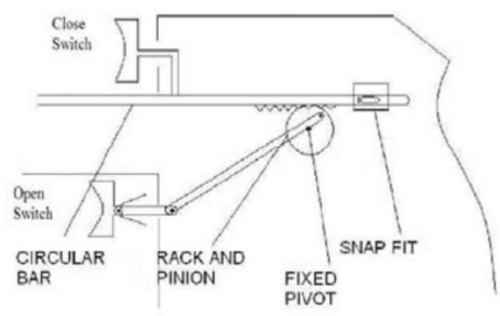

Fig. 4: Mechanism Concept 2

The merits of this mechanism are that it's a purely mechanical mechanism. But the complexity of the linkages and the feasibility of its working prompted over further improvement of this concept.

3.3 Mechanism Concept 3

In this Concept, the Open switch is connection to the circular bar with the help of a roller, and slot cylinder mechanism. Snap locks the forceps at open and close positions. Open switch movement results in forward motion of the circular bar simultaneously pushing the close switch forward as it is directly connected to the circular bar.

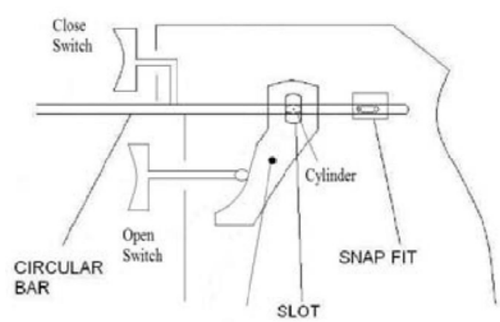

Fig. 5: Mechanism Concept 3

Complexity is involved in the working as well as the manufacturing of this mechanism.

3.4 Mechanism concept 4

In this Concept, the scope of rack and Pinion is expanded using a 3 gear mechanism by which the Open switch is connected to the circular bar. The increase in gear size connected to the rack of circular bar is the result of mechanical advantage. Snap locks the movement at Open and close positions. Close switch is directly connected to the circular bar.

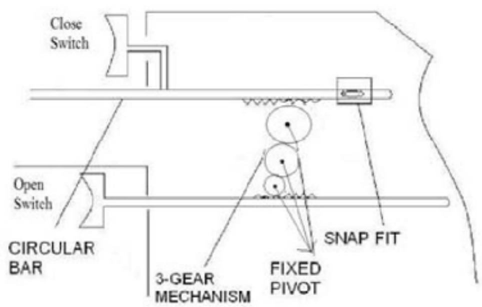

Fig. 6: Mechanism Concept 4

The merits of this advantage are its purely mechanical, having a mechanical advantage over the existing mechanism and interlocks the forceps at open and close positions.

3.5 Mechanism Concept 5

Close switch is connected to the circular bar with the help of two linkages and same is the case with Open switch. The movements of one switch results in the movement of links resulting in forward and backward movement of the circular bar with an increase in mechanical Advantage according to the link sizes taken. Snap locks the circular bar at open and close positions.

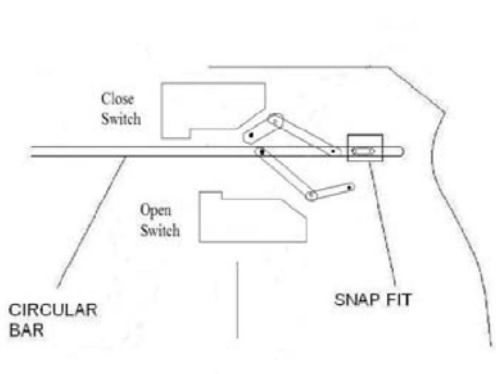

Fig. 7: Mechanism Concept 5

This Concept has a feasibility of having the highest mechanical advantage over others and has better manufacturability.

3.6 Concept Selection

Concept Selection is done preparing a concept scoring matrix for the above concepts. Concept scoring is used as it gives an increased resolution differentiating among competition concepts. It weighs the relative importance of the selection criteria and focuses on more refined comparisons with respect to each criterion. After a careful study over the requirements, a Concept scoring matrix with selective criteria for the present application (Fig. 8) has been prepared. The selection criteria for the matrix included Simplicity of Mechanism, Number of parts, Manufacturability of parts, Mechanical Advantage, Sturdiness, or Robustness of mechanism, Standard Components / Hardware, Cost, Safety, Maintenance. The Matrix obtained is as below.

Concept Scoring Matrix											
		1		2		3		4		5	
Selection Criteria	Weight	Rating	Weigh	Rating	Weight	Rating	Weight	Rating	Weight	Rating	Weighte
Simplicity of Mechanism	10	8	80	7	70	6	60	7	70	9	90
Number of parts	10	8	80	6	60	6	60	7	70	8	80
Manufacturability of parts	15	8	120	6	90	6	90	7	105	9	135
Mechanical Advantage	10	7	70	7	70	6	60	7	70	9	90
Robustness of mechanism	15	6	90	6	90	5	75	6	90	7	105
Standard Components	15	6	90	6	90	6	90	8	120	7	105
Cost	10	8	80	6	60	6	60	6	60	8	80
Safety	15	6	90	6	90	5	75	7	105	9	135
Total Score											
Rank	100	700		620		570		690		820	
		2		4		5		3		1	

Fig. 8: Concept Scoring Matrix

The scores divulge the domination of the 5th and 1st mechanisms over others.

4 Summary and Outlook

Surgical Instrument design is a high precision involved Innovative field still to be explored. Robotics and Automation in surgeries is a cutting edge development in surgery that will have far reaching implications. While improving precision and dexterity, this emerging technology allows surgeons to perform operations that were traditionally not amenable to minimal access techniques. As a result, the benefits of minimal access surgery may be applicable to a wider range of procedures. New technologies, such as virtual reality, haptics, and telementoring [9], can powerfully ally with surgical robots to create a new medium for acquisition and assessment of surgical skills through simulation of all operations. Realizing revolutionary applications of Minimum Invasive surgery to health or environmental problems raises new control challenges. The design and the development of automated surgical equipments with high performance should be addressed via simulation to help pave the way for future applications in biomedical engineering problems.

Concepts developed were then scored according to a selective criteria as per the requirements then scored to select the best out of proposed concepts meeting the requirements of improving the surgical device factors such as safety, individual control of jaws and locking at open & closed positions.

Acknowledgement

I take this Opportunity to thank each and everyone who have helped in making my thought at Imagination into reality, an attempt to improve a vital part of Bio - medical Engineering.

5 References

[1] Robert O. Parmley P.E , "*Machine devices and components illustrated sourcebook*" McGraw Hill 2005

[2] Neil Sclator & Nicholas P.Chironis, "*Mechanisms and Mechanical devices*" 3rd Edition

[3] John J. Uicker, Gordon R. Pennock and Joseph E. Shigley , "*Theory of Machines and Mechanisms*" Third Edition Oxford University Press,2003, Canada

[4] Joseph E. Shigley, Charles R. Mischke "*Standard handbook of machine design*" Second Edition 1996

[5] Robert L Norton "*Design of machinery an introduction to the synthesis and analysis of mechanisms and machines*" Second edition 1999

[6] R.S.Khurmi, J.K.Gupta "*Theory of Machines*" S.Chand

[7] Karl T.Ulrich, Steven D.Eppinger "*Product design and development*", 3rd Edition Tata McGraw-Hill

[8] Ghosh A "*Theory of Mechanisms & Machines 3rd Edition*" Affiliated East-west Press Pvt Ltd, 2000

[9] Michael R. Treat, "*Computer-Integrated Surgery", chapter "A Surgeon's Perspective on the Difficulties of Laparoscopic Surgery*", pages 559–560. MIT Press 1995