Innovative Design of Intervention Module for Vessel Intervention Surgery Robot Based on TRIZ Theory

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Abstract. Functional model of interventional surgery robot system is obtained based on the analysis of interventional surgery needs. Combining the original design results, functional models are further analyzed. An innovative design method of interventional surgery robot based on TRIZ theory is proposed to simply the mechanism and perfect function. The problem model is defined by using TRIZ method. System tailoring strategy based on functional model and invention principle based on conflict resolution theory are combined for solving the design problem. Then, the new structural scheme is given based on the above analyses. The synthesized structural scheme has been greatly simplified. Finally, the TRIZ theory is used to evaluate the innovative design scheme. It is concluded that the improvement of the new scheme relative to the original scheme follows the evolutionary mode of expansion and simplification of the technical system, and conforms to the evolutionary rule of the technical system.

Introduction

With the aggravation of social aging, cardiovascular disease (CVD) and stroke produce immense health and economic burdens in globally[1].

Minimally invasive cardiac surgery, where access to the heart is typically achieved through a left or right minithoracotomy, may alleviate some problem which caused by larger incision operation. Minimally invasive cardiac surgery is as safe as conventional surgery and could reduce costs due to a shorter period spent in ICU[2]. It has become to the trend of clinical medicine because of its advantages of fewer traumas, less pain, faster recovery, and lower radiation damage of doctors and patients[3].

Endovascular interventions include a variety of techniques that give access to the vascular system through small incisions[4]. This is one of the main methods to treat coronary artery embolism at present.

Some disadvantage still exist. Firstly, without adequate radiation protection equipment and training, long-term occupational exposure to X-rays will increase the risk of serious adverse effects among vascular surgeons[5]. Secondly, doctors should concentrate their energies highly during the operation, which can easily cause fatigue of doctors, thus failing to ensure the efficiency and effectiveness of the operation, and there may be dangerous situations such as blood vessel puncture, which will cause great harm to patients[6].

With the development of robotic technology, the application of robotic technology in minimally invasive surgery can solve these shortcomings in minimally invasive surgery[7,8]. The robotic system for cardiovascular interventional surgery aims at greatly reducing the harm of X-ray to doctors during the operation, reducing the influence of fatigue and unstable manual operation on the quality of surgery.

TRIZ theory, which was born in the former Soviet Union, has a relatively complete process for solving innovation problems and is highly operable. It is very suitable for application in product innovation design and innovation improvement of existing institutions, and has universal guiding significance for product concept innovation[9,10].
Based on the research of early interventional surgery robots, combined with TRIZ innovative theory and related methods, the purpose is to improve the existing technology system and propose a new design of vascular interventional surgery robots.

**Functional Analysis of Vessel Intervention Robot System**

Vessel interventional surgery robot is used for assisting doctor with completing the operation to insert a guide wire into specific lesions location in the blood vessel, to examine the vascular embolism and to expand balloon and stent. The main function of the technical system is to deliver the guide wire to a specific location. In order to achieve smooth delivery, it is necessary to rotate the guide wire at the branch vessel, so that the front elbow of the guide wire turns to the branch vessel, so its auxiliary function is to rotate the guide wire. The guide wire itself has certain flexibility, and it will bend and droop without support, which is not conducive to delivery, so its auxiliary function is to support the guide wire. In the process of the guide wire advancing, it is necessary to feel the resistance of the front end in real time so that the doctor can react quickly and avoid puncturing the vessel wall. Therefore, the resistance of the front end should be measured as the assistant function of the system. Furthermore, the guide wire needs to be inserted into the human blood vessels, and the requirements of disinfection and cleaning to meet the medical conditions are put forward for its operating device, which is the fourth auxiliary function of the system. In a word, the robot system needs to include one core function and four auxiliary functions. On the basis of the above functions, a technology system of vascular interventional surgery robot is expected which can deliver and rotate the guide wire simultaneously.

**Original Functional Model Based on Functional Analysis**

According to the analysis of system requirements and functions mentioned above, the original system is implemented separately from the perspective of single functional module. The functional model are shown in Figure 1.

![Original functional model of system.](image)

**Improvement of Functional Model**

Aiming at the problems of complex system structure and inconsistent rotation and movement of the original system, an improvement based on TRIZ innovative design theory is proposed. On the basis of the above function analysis, the most direct related TRIZ theory to simplify the mechanism is the clipping method of the technical system. Therefore, the system structure simplification is attempted by using the technology system tailoring strategy based on the system function model. Whether the functional model is suitable after tailoring depends on whether there is a specific solution corresponding to it. When solving the specific solution, 40 inventive principles can be used to solve technical problems based on conflict matrix. So in order to determine the overall design idea, the first step is cutting the technical system, and then seeking the corresponding...
inventive principles. For the problem of inconsistency between rotating and delivery, it is related to
the action principle of the whole mechanism and the interaction between sub-functions. It can be
used as a condition for screening and evaluating schemes because of its dependence on the designed
structural carrier.

Solution Strategy of Intervention Module Design Based on TRIZ
In order to further improve the technical system, firstly, the corresponding auxiliary functional
modules are cut by the tailoring strategy of the technical system, which will greatly simplifies the
system.

The basic functional model unit for the implementation of technology system tailoring strategy is
shown in Figure 2.

![Figure 2. Basic functional model unit.](image)

**Figure 2. Basic functional model unit.**

Tailoring Strategy of Technology System:
1) without B, then A can be cut;
2) B has the function of A, then A can be cut;
3) C which in the system has the function of A, then A can be cut;
4) C which outside the system has the function of A, then A can be replaced.

**Technology System Tailoring**
The function of the rotating part is to rotate the guide wire. If the following conditions are met, the
rotating part can be cut:
1) No guide wire needs to be rotated.
2) The guide wire can rotate by itself.
3) Other components in the technical system can assist the guide wire to complete rotation.

The first one is inconsistent with the requirement of the technical system; the interventional guide
wire used at present belongs to one-time consumables and has no rotating function, and the second
one cannot be realized; therefore, considering the third cutting strategy, the mechanism can be
simplified by means of moving parts, thus further considering the specific implementation method.
When the moving and rotating action actuators are combined into an Integrated Device, they share a
clamping function, which integrates the three actions of clamping, moving and rotating as a
comprehensive functional module.

Furthermore, the two functions of force measurement and disinfection are relatively independent,
which need to be realized according to the basic integrated functional modules designed above, so
they are not considered here. The resulting functional model is shown in Figure 3.
Conflict and its Resolution Principle

According to the analysis of the overall function of the system and the existing ways of implementation, the problem is further analyzed with the conflict theory. According to the 39 general engineering parameters in TRIZ theory, considering that in the process of system improvement, the main purpose is to simplify the structure of the system on the basis of guaranteeing its functions. Therefore, it is considered that the system needs to improve its functional parameters: 36 complexity. In the process of system simplification, it is necessary to combine the moving finger and the rotating finger, which may lead to the increase of the volume and mass of the moving part. Therefore, the deteriorating function parameter is chosen as the volume of 7 moving objects, and the inventive principle is solved for the selected engineering parameters.

By looking up the conflict matrix of TRIZ theory, the corresponding inventive principles can be obtained: 34 discarding and repairing, 26 replicating, 6 multipurpose.

Solution: With the help of 34 discarding and repairing and 6 multi-purpose combination of the invention principle, the three functions of clamping, delivering and rotating are integrated, and the realization method of improving disinfection function is considered. A disposable discardable component is used instead of a quick disassembly and assembly mechanism.

Because the delivery speed requirements are different between the situation of delivery in the aorta and in a branch vessel. If a single delivery mechanism is used, on the one hand, it needs to adjust the speed, on the other hand, it needs to design an auxiliary support device. Thus, it is thought of the 26 replicates in the invention principle, which play the role of fast delivery and auxiliary support by replicating a delivery finger after the delivery finger along the direction of the guide wire. The replicated delivery finger, because it is fast delivery, and does not need to rotate in the aorta, so the system only need copy the mobile function module, and the rotary function module is not needed.

Structural Design of Interventional Surgery Robot

The guide wire intervention device mainly solves the problem that the delivery and rotation of the guide wire need to be executed simultaneously and the resistance measurement of the front end of the guide wire during the intervention process. The innovative design idea of mechanism is shown in Figure 4.
a) With the help of two sets of gears on the rack sliding module, the front and rear moving fingers move at different speeds, respectively, to achieve rapid delivery in the great artery and slow regulation in the branch vessels. The first moving finger near the interventional end realizes slow regulation, while the second moving finger far from the interventional end realizes fast delivery, and supports each other in the delivery process. No additional supporting structure is needed.

b) The first moving finger is rotated by means of an electric turntable mounted on the mobile gear support (as shown in Fig. 5), which realizes the rotation of the guide wire, retains the reliability of the clamping rotation method, reduces the rotating parts and reduces the vibration in the process of rotation.

c) The electric turntable is mounted on the first moving finger base near the intervention end, and moves synchronously with the first moving finger, thus realizing simultaneous delivery and rotation.

d) The first moving finger near the intervention end is connected with a hollow tension pressure sensor at the back end. When the front end has resistance, the first moving finger acts on the pressure surface of the tension pressure sensor to measure the resistance at the front end of the guide wire without adding other auxiliary devices and changing the principle of delivery and rotation.

Conclusion

(1) In the process of top-level conceptual design and improvement, the function analysis method is used to get a relatively macro-functional model. Combining with the tailor strategy, the top-level functional modules are cut, which is more conducive to the simplification of the system and improve the efficiency of tailoring.

(2) According to the structure design of the tailored functional module, the conflict and its
solution principle are used to analyze, and the goal is to point to 40 inventive principles, which is more conducive to defining the specific design scheme.

(3) According to the above theory, the improved technical system retains the function of the original system, solves the practical problems such as the mobile rotation cannot be carried out simultaneously, and simplifies the system structure, reduces the number of parts, reduces the difficulty of processing and installation, and reduces the cost, so the system has been further effectively optimized.

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