Proceedings of the 2018 IEEE
International Conference on Cyborg and Bionic Systems
Shenzhen, China, October 25-27, 2018

A novel intestinal microcapsule endoscope robot with biopsy function

Xiaofei Pan[1], Tao Ma[1], Peng Li[1], Xin Jiang[1], Shuang Song[1]*, Max Q.-H. Meng[2], *Fellow, IEEE*

***Abstract*—This paper presents an intestinal microcapsule endoscope robot with a biopsy function. The designed microcapsule robot includes two capsule shells and a biopsy function module. Inside the capsule housing is provided with a sampling slot, which extends from the inside of the capsule housing to the outer capsule; the sampling device is composed of a rack module and a biopsy module connected to each other; the biopsy module is arranged toward the outlet of the sampling slot, and the rack module is set in the sampling tank. The driving device includes a motor, a driving motor shaft, and a driving gear connected with the motor through the driving motor shaft, and the driving gear and the rack module are engaged. The transmission structure of the rack and gear combination is simple in construction, transmission movement is accurate and stable, and the ingenious design of miniature barb causes minimal surgical trauma. Through simulation analysis and testing, we have manufactured corresponding products. Experimental tests demonstrate that the designed capsule robot can perform biopsy successfully.**

***Index Terms*—microcapsule robot, biopsy, structure design.**

I. Introduction

With the development of capsule endoscopes, there has been a trend of capsule endoscopes replacing traditional endoscopes [1, 2]. There are several commercial capsule endoscopes available currentlysuch as PillCam SB2, EndoCapsule MiroCam, OMOM PillCam, and Colon 2 PillCam ESO2 [2]. However, the functions of these capsule endoscopes are relatively simple and cannot perform biopsy procedures.

Due to the development of science and technology and the need for medical treatment, many researchers are integrating biopsy surgical functions with robots. Kong Kyoung-chul et al. [3] designed a micro biopsy module for micro capsule robots consisting of a trigger with a paraffin block, a rotating tissue cutting razor with a torsion spring and a controller. The module enables the capsule endoscope robot to obtain the sample tissue in the small intestine that cannot be obtained by the conventional biopsy device. The experiment has successfully obtained the biopsy sample of the small intestine of the cow and the rabbit. Sunkil Park et al. [4] proposed a microbiopsy using microspike, which using a torsion spring as an operating member and a shape memory alloy as a trigger member. Kyoungchul Kong et al. [5] proposed a biopsy device using shape-memory-alloy (SMA) as anchor and biopsy using cylindrical razor. Yim S et al. [6] proposed a method using microgripper with a low μ-gripper recovery (3%).

This work is supported by the Science and Technology Innovation Committee of Shenzhen under Grant JCYJ20170307151715204 and Grant JCYJ20170413110250667.

[1] Xiaofei Pan,Tao Ma, Peng Li, Xin Jiang, Shuang Song are with School of Mechanical Engineering and Automation, Harbin Institute of Technology (Shenzhen), Shenzhen, China, 518055.

[2]Max Q.-H. Meng is with Department of Electronic Engineering, the Chinese University of Hong Kong, Hong Kong, China, and affiliated with the State Key Laboratory of Robotics and Systems (HIT), Harbin Institute of Technology, China.

*Corresponding author: Shuang Song, mail: songshuang@hit.edu.cn

To date, capsule endoscope robots with biopsy function are complex relatively in structure. Since shape memory alloys have the disadvantages of high energy consumption and slow response, while heating shape memory alloy wires will cause damage to the tissues [7], the use of shape memory alloys limits some performances of the capsule robots.

In this article, we describe a novel intestinal microcapsule endoscope robot with biopsy function in detail. It is necessary to consider structural stability and reduce biopsy damage to the intestinal tissue. In our design, minimally invasive surgery is performed using a biopsy capsule provided with miniature barbs. Miniature barbs are placed side by side and have a certain gap, which allows accurate grasping, less surgical trauma and patient suffering. The structure of biopsy module is simple, and the transmission movement of rack and gear is accurate and stable. We first design and simulate models based on CAD, Adams and Ansys, and then conduct manufacturing and testing in vitro.

II. Model design and simulation

A. Design Model

The microcapsule endoscope robot with biopsy function should not be larger than 15mm(D)$\times$30mm(L), or it will be hard to swallow [7, 8].

As the capsule endoscope robot needs to integrate cameras, drivers and other modules in the future, biopsy module space should be moderate. As shown in Fig.1, the designed biopsy function module with thickness of 4mm, and diameter of 12mm. Fig.2 shows the final design module as more modules have been integrated. We have manufactured the model prototype except integrated searchlight, camera. The manufacturing part will be described in the next section in detail. As shown in Fig.1 and Fig.2, the controller controls the motor to rotate forward. The driving motor shaft drives the driving gear to drive the rack module to move along

978-1-5386-7355-3/18/$31.00 ©2018 IEEE

the sampling groove to the outside of the capsule, thereby driving the biopsy module out of the capsule. The biopsy module captures the living tissue and the taken living tissue is stuck in the biopsy module by the mini barb, and then the controller controls the motor to reverse. The biopsy module moves inside the capsule by the driving motor shaft actuates the driving gear to drive the rack module. The above is the functional description of biopsy.

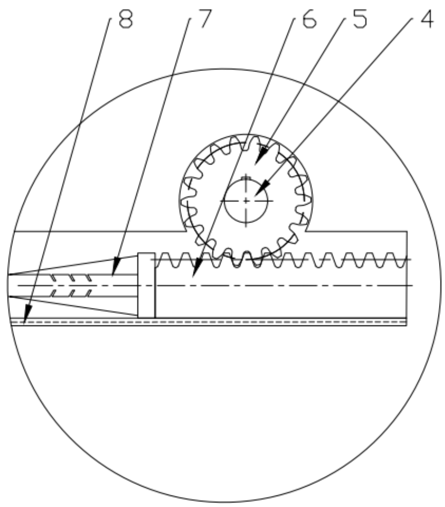

Fig. 1. Schematic diagram of biopsy function module.
4 - Drive motor shaft, 5 - Drive gear, 6 - Rack module,
7 -Biopsy module, 8 - Slot.

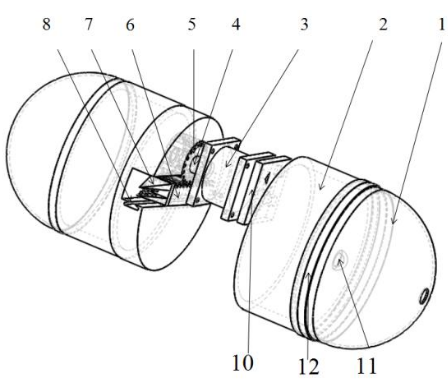

Fig. 2. Schematic diagram of a novel intestinal microcapsule endoscope robot with biopsy function.
1- Capsule top, 2 - Capsule outer tube, 3 - motor, 4 - Drive motor shaft, 5 - Drive gear, 6 - Rack module, 7 - Biopsy module, 8 - Slot, 10 - Controller, 11-Searchlight, 12-camera.

As shown in Fig.3, the biopsy module is a biopsy forceps, a micro barb is arranged on the inner side of the jaws. The micro barbs are symmetrically distributed on the inner walls of both sides of the biopsy forceps. This design is for minimally invasive surgery and less patient suffering. The biopsy forceps size parameter is shown in Fig.4.

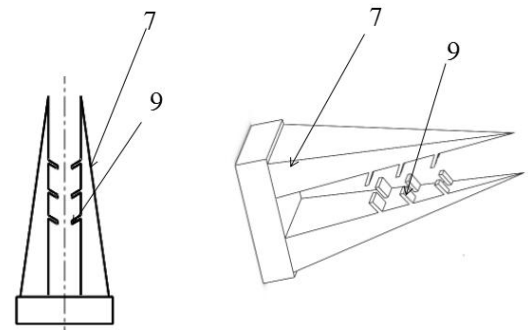

Fig. 3. Biopsy forceps detail. 7-Biopsy module, 9-mini barb.

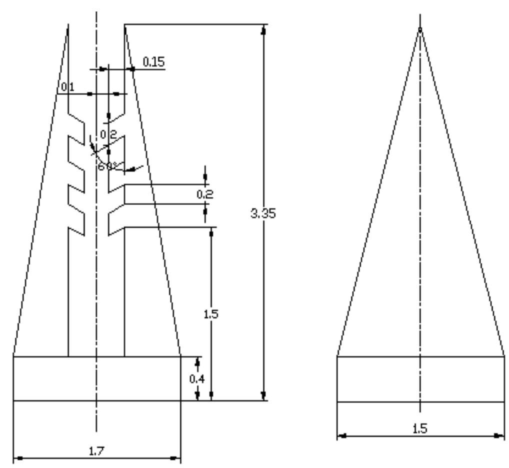

Fig. 4. Biopsy forceps parameter(mm).

B. Simulation

Before manufacturing the actual object, the biopsy module was simulated to analyze the degree of injury of the puncture force to the intestinal tissue and whether the force meets the requirements. For Adams excels in dynamic analysis, ANSYS excels in finite element analysis, we combine them to analyse the the designed module. The penetration force of different tissues in the gastrointestinal tract is not the same. We did not find clinical data on tissue parameters related to the gastrointestinal tract. currently. The micro-ecology of the intestine is related to the liver closely and affects each other[9]. Through liver intestine axis, intestine and liver are closely related in anatomy and function [10]. Therefore, we used liver-related parameters to analyze the biopsy process. Density is taken as 1.051g/mL [11]. Young's modulus is 25.3kPa, Poisson's ratio is 0.48 [12]. Other materials used for simulation are made of stainless steel. Density is taken as 7.750g/cm3. Young's modulus is 19.3GPa, Poisson's ratio is 0.31.

Fig.5 is the model after importing Adams. Because Adams excels in dynamic analysis, we analyse the force of biopsy

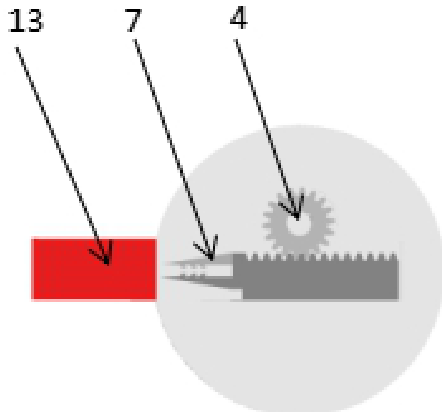

Fig. 5. simulation in Adams. 4 - Drive motor shaft 7 - Biopsy module, 13-tissue

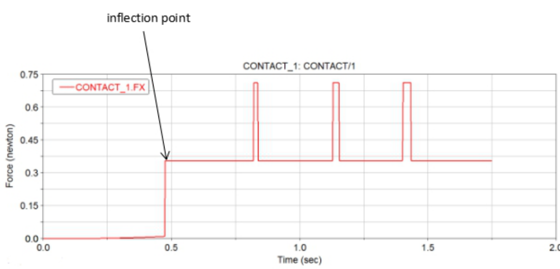

Fig. 6. The graph of puncture force simulation

forceps and tissue contact in Adams. From Fig. 6 it can be seen that the infection force is 0.3559 N when the biopsy forceps is inserted in the tissue. The stepping angle of a typical small DC stepper motor is 18 degrees. Too slow or too fast may cause instability. Here we set the motor shaft speed to 54 degrees per second. Compared with other desion[1, 3, 4], this infection force is moderate in our design.

To characterize the degree of damage and guide further improvement and optimization of biopsy structures, we used ANSYS to analyze the stress and strain of gastrointestinal tissue models under the biopsy function module.

We apply the puncture force obtained by Adams and the initial velocity of the biopsy forceps. Importing this as a boundary conditions into ANSYS, we get Fig. 7-12. The initial speed of biopsy forceps is 0.2025mm/s get by $v = w \times r$.

When meshing objects, the speed and accuracy of mesh generation should be considered. The biopsy forceps grid size is 0.25mm and the tissue grid size is 3mm. From Fig.7, it can be seen that the mesh is evenly distributed, which will help produce a relatively reasonable result. In Fig 8, mark number 1 represents the initial state of biopsy forceps, mark number 2 represents the state of insertion tissue, and mark number 3 represents the biopsy tissue. We use stress and strain analysis to characterize tissue damage. Fig.9 represents the deformation of tissue. In our design, the insertion depth is

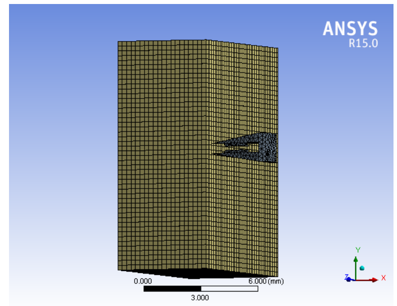

Fig. 7. The graph of mesh

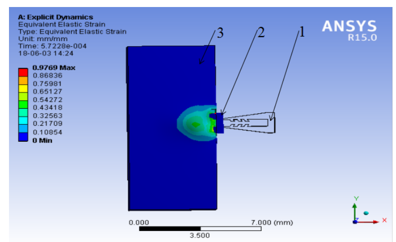

Fig. 8. The graph of Equivalent Elastic Strain 1

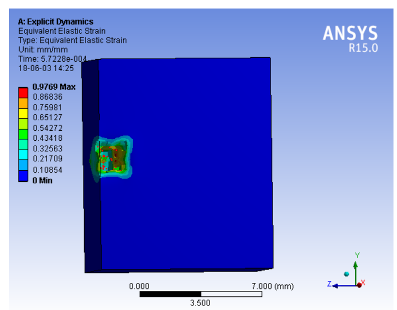

Fig. 9. The graph of Equivalent Elastic Strain 2

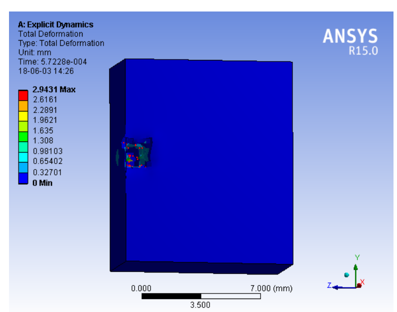

Fig. 10. The graph of Deformation

variable, which will not only be effective for mucosal tissue acquisition but also for submucosal tumors[13].

From Fig.12, we can see that the convergence is good. The graph of equivalent stress in Fig.11 is what we really care about. For the maximum negative pressure that the intestine can withstand is about -3.7×10^7 KPa [14, 15], the maximum value shown in Fig.11 is 0.032597MPa which

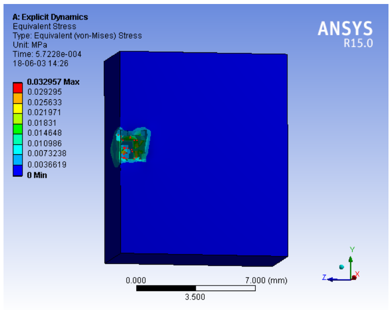

Fig. 11. The graph of Equivalent Stress

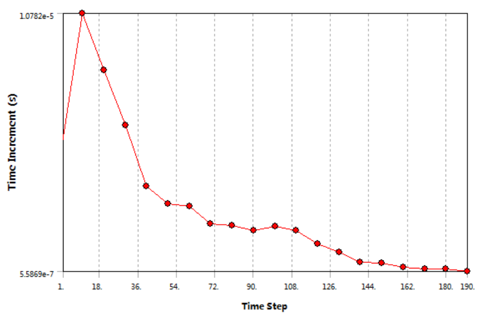

Fig. 12. Iteration time curve

generate a tiny impact on the intestine.

III. Manufacture and Experiment in vitro

We take stainless steel 17-4ph as biopsy function module material. Biopsy function module manufacturing process has three major parts: (1)Gear: In the process, first turning the profile, then cut the tooth profile according to the gear parameter line. Finally, the shaft is lightly ground to achieve better movement fit accuracy with the base. (2)Sampling Rack: Firstly, the outer contour and rack tooth profile are cut by wire cutting, and the upper milling machine cuts out the inclined surface, and finally the surface is polished. (3)Base: First use the lathe car out of the outline, and then wire out the slot of the sampling rack, then cut the bottom slot with argon arc welding wire, then use the milling machine to mill the gear shaft slot, and polishing deal finally.

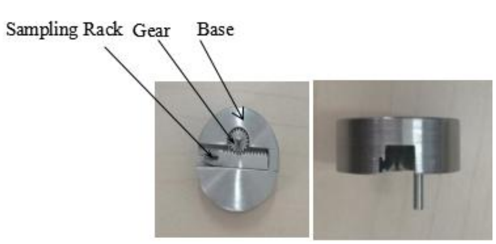

Fig. 13. Biopsy function module with 2 times prototype

Fig. 13 shows the final biopsy function module prototype which consists of sampling rack, gear, and base. Fig. 14 shows the final prototype with shells. Coupling and stepper motor are integrated in shell 1, while shell 2 is reserved for other functions. The shells is made of ABS material using 3D printing technology.

Fig. 14. Intestinal microcapsule endoscope robot module.
1-shell 1,2- biopsy module,3-shell 2,4-Couplings,5-Micro stepper motor

Fig. 15 shows the vitro experiment in pig intestine. Repeated experiments found that biopsy forceps can obtain tissue sample successfully. As shown in Fig.16 , we measured this puncture force with a force sensor. First we turn the display instrument indicator to zero as shown in Fig.16(1), then we test max puncture force and a result of 0.38N is obtained. This data are close to simulation which is moderate in our design [1, 3, 4].

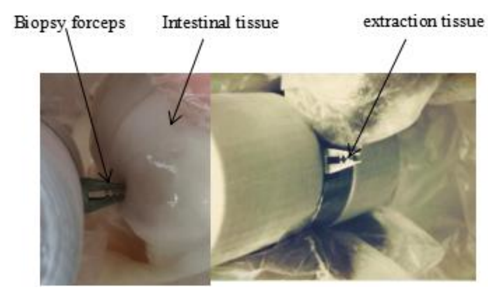

Fig. 15. Vitro experiment in intestine tissue

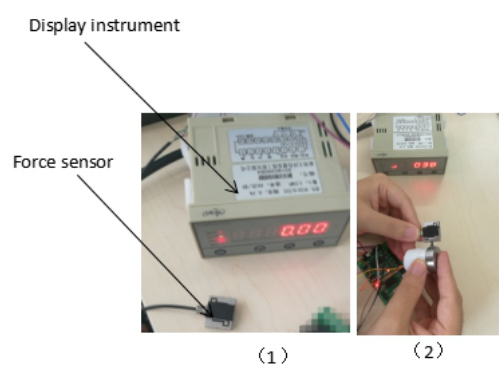

Fig. 16. Puncture force detection

IV. Conclusion and Future work

In this article, a novel intestinal microcapsule endoscope robot with biopsy function was developed. We have produced prototype finally and perform vitro experiment in pig intestine successfully. Experiment data are close to simulation data which is moderate in our design. We use stress and strain analysis to characterize tissue damage. The maximum value of stress generate a tiny impact on the intestine. Simulating biopsy function module helps to provide guidance for research on intestinal tissue injury.

The accurate simulation results have positive guiding significance for the experiment. In the future, we will further analyse and optimize the structure, and add a positioning scheme to the capsule reserved space to achieve accurate sampling.

REFERENCES

[1] S. Park, K. I. Koo, G. S. Kim, S. M. Bang, S. Y. Song, J. W. Byun, C. N. Chu, and D. Cho, *A Novel Micro-Biopsy Actuator for Capsular Endoscope using LIGA Process*, 2007.

[2] P. Valdastri, M. Simi, and R. J. W. Iii, "Advanced technologies for gastrointestinal endoscopy," *Annual Review of Biomedical Engineering*, vol. 14, no. 1, pp. 397–429, 2012.

[3] K. C. Kong, J. Cha, D. Jeon, and D. I. D. Cho, "A rotational micro biopsy device for the capsule endoscope," in *Ieee/rsj International Conference on Intelligent Robots and Systems*, 2005, pp. 1839–1843.

[4] S. Park, K. Koo, S. M. Bang, J. Youp Park, S. Y. Song, and D. Dan'Cho, "A novel microactuator for microbiopsy in capsular endoscopes," *Journal of Micromechanics & Microengineering*, vol. 18, no. 18, p. 025032, 2008.

[5] K. Kong, S. Yim, S. Choi, and D. Jeon, "A robotic biopsy device for capsule endoscopy," *Journal of Medical Devices*, vol. 6, no. 3, p. 031004, 2012.

[6] S. Yim, E. Gultepe, D. H. Gracias, and M. Sitti, "Biopsy using a magnetic capsule endoscope carrying, releasing, and retrieving untethered microgrippers," *IEEE transactions on bio-medical engineering*, vol. 61, no. 2, p. 513, 2014.

[7] S. S. Mapara and V. B. Patravale, "Medical capsule robots: A renaissance for diagnostics, drug delivery and surgical treatment," *Journal of Controlled Release*, vol. 261, 2017.

[8] L. Liu, S. Towfighian, and A. Hila, "A review of locomotion systems for capsule endoscopy." *IEEE Reviews in Biomedical Engineering*, vol. 8, no. 1, p. 138, 2015.

[9] Masami, Minemura, Yukihiro, and Shimizu, "Gut microbiota and liver diseases," *World Journal of Gastroenterology*, vol. 21, no. 6, pp. 1691–1702, 2015.

[10] Giulia, Paolella, Claudia, Mandato, Luca, Pierri, Marco, and Martina, "Gut-liver axis and probiotics: Their role in non-alcoholic fatty liver disease," *World Journal of Gastroenterology*, vol. 20, no. 42, pp. 15 518–15 531, 2014.

[11] B. A. Overmoyer, C. E. Mclaren, and G. M. Brittenham, "Uniformity of liver density and nonheme (storage) iron distribution." *Archives of Pathology & Laboratory Medicine*, vol. 111, no. 6, p. 549, 1987.

[12] S. P. Dimaio, "Modelling, simulation and planning of needle motion in soft tissues," Ph.D. dissertation, 2003.

[13] D. Son, M. D. Dogan, and M. Sitti, "Magnetically actuated soft capsule endoscope for fine-needle aspiration biopsy," in *IEEE International Conference on Robotics and Automation*, 2017, pp. 1132–1139.

[14] J. H. Liu, S. Q. Wang, and D. Y. Liu, "Investigation of miniature robot-induced injury in intestinal tract," *World Chinese Journal of Digestology*, 2006.

[15] L. Liang, P. Hui, H. U. Guan-Yu, and H. L. Hou, "Numerical simulations on injury to human intestinal walls produced by spiral micro-robots," *Journal of System Simulation*, 2011.