The control method of peripheral venous catheters automatic insertion using force measurement

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Introduction

The aim of this work is to develope a feedback unit based on a strain gage force sensor integrated into a robot-assisted venipuncture system to control the rectilinear catheter insertion in order to minimize post-injection complications caused by mechanical damage to vessel wall [1-3].

When the carriage of an automated system with a installed catheter moves, the catheter exerts pressure on the strain gage force sensor, which changes its own resistance in proportion to the force acting on it.

Materials and Methods

To obtain the characteristic signals at the moment of vessel wall puncture, a laboratory stand was designed. The mechanical and electrical part of the stand includes: a carriage with guides, a rack gearing, a DC motor with GM12-N20VA gearbox (500: 1 ratio), an L293D motor driver and a signal recording unit. The signal recording unit consists of the following main elements:

- FlexiForce A201 strain gage force sensor (maximum applied force 4 N) from the Tekscan manufacturer, which is attached to the carriage [4];
- inverting voltage converter ICL7660;
- MCP602 operational amplifier for realizing an inverting amplification stage;
- Arduino Nano platform with ATmega 328 microcontroller with built-in 10-bit ADC module.

Experimental studies were conducted on different biological phantoms. A strain-gage force sensor was installed between the carriage, which drives the catheter and the catheter itself. This position allows to achieve the maximum sensitivity of the strain gage sensor to the catheter at the moment of puncture of the phantom. The used biological phantom in the first series of experimental studies is presented in Figure 1, the biological phantom is a gelatin, which simulate the soft tissues and an artificial tissue vessel as well as a sealed food layer in a gelatin.The food sheath was chosen to simulate the vessel wall, because it is structural similarity. In the second and third series of experimental studies, the soft tissues were simulated by a pork meat fragment; the blood vessel in the first case was simulated by a soft rubber tube with an internal pressure of 136 mm of water. (Mean venous pressure), in the second case - using a thin-walled tube made of polyvinyl chloride. The main principle of the three types of phantoms is to simulate the transition from soft tissue to the vascular bed with a higher density border.

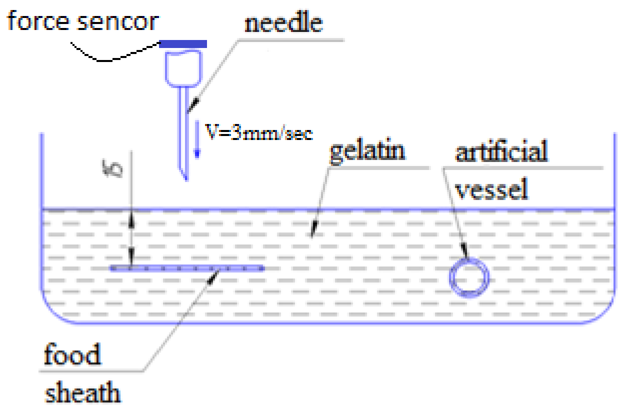

Figure 1: The image of the phantom

Analyzing the obtained signals during the third series of experiments (the characteristic form of signal is shown in Figure 2), it was difficult to uniquely determine the moment of vessel wall puncture. Therefore, it was decided not to use these signals to estimate the characteristic parameters of the signal as well as during the algorithm designing.

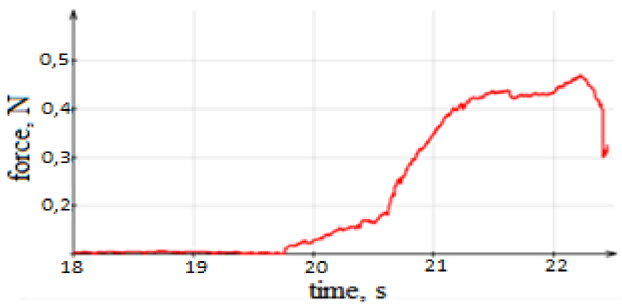

Figure 2: Characteristic signal form

The obtained signals in the first and second series of experiments had a similar shape, which is shown in Figure 3. The following signal characteristic parameters were selected for their further analysis:

- punching duration (deltaT), s;
- peak value, N;
- local minimum after puncture, N;
- the ratio of the maximum and minimum.

The results of the experiments are shown in Tables 1-3.

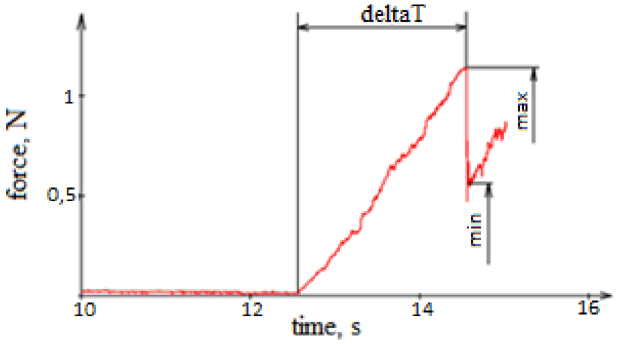

Figure 3: Selected characteristic signal parameters

Table 1: The results of the first series of experiments, the phantom: food sheath

№.	peak value (max), N	local minimum after puncture (min), N	ratio $\frac{max}{min}$	Punching duration (deltaT), sec
01:01	0,97	0,45	2,15	1,96
01:02	1,14	0,55	2,07	1,94
01:03	1,32	0,8	1,65	2,35
01:04	1,19	0,6	1,98	2,17
01:05	1,24	0,61	2,03	1,97
Average	1,17	0,6	1,98	2,08
Deviation	0,131	0,127	0,192	0,178

Table 2: The results of the second series of experiments, the phantom: artifition vessel

№.	peak value (max), N	local minimum after puncture (min), N	ratio $\frac{max}{min}$	Punching duration (deltaT), sec
02:01	0,43	0,25	1,72	1,4
02:02	1,08	0,37	2,92	1,67
02:03	0,76	0,39	1,95	1,38
Average	0,76	0,34	2,2	1,48
Deviation	0,32	0,07	0,64	0,16

Table 3: The results of the third series of experiments, the phantom: a rubber tube with an internal pressure of 136 mm of water article

№.	peak value (max), N	local minimum after puncture (min), N	ratio $\frac{max}{min}$	Punching duration (deltaT), sec
03:01	0,35	0,17	2,06	1,61
03:02	0,48	0,25	1,92	1,76
03:03	0,4	0,2	2	2,312
03:04	0,48	0,33	1,45	2,28
Average	0,43	0,24	1,86	1,99
Deviation	0,064	0,07	0,28	0,36

Results

Based on the results of the experimental studies, discrete signals were obtained, which were used to develop an algorithm for recognizing the vessel wall puncture. The algorithm is based on the analysis of the amplitude-time parameters of the obtained signals. It is shown that the applied electrical circuit for signal recording satisfies the assigned task. It is established that the received signals are qualitatively similar to the signal from the literature sources [5] and have a coincidence in order of the measured value (force acting on the force sensor). Based on the literature data, a conclusion about the permissible adjustment of the measuring equipment was made.

Conclusions

As a result of this study, a feedback module was developed to control the introduction of a peripheral catheter on the basis of a strain gage force sensor capable of detecting the moment of vessel wall puncture.

References

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