

# Sensing System for Intra-Abdominal Pressure Measurement

**Teodor Tóth, Monika Michalíková, Jozef Živčák**

Technical University of Košice, Faculty of Mechanical Engineering, Department of biomedical engineering and measurement, Letná 9, Košice, 04200 Slovakia  
teodor.toth@tuke.sk; monika.michalikova@tuke.sk; jozef.zivcak@tuke.sk

**Richard Raši**

Louis Pasteur University Hospital, Rastislavova 43, Košice, 04 001 Slovakia  
rasi@unlp.sk

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*Abstract: The development of technology and information technology offers new possibilities for detecting intra-abdominal pressure (IAP) in critically ill patients. Presently, non-invasive measuring through the monitoring of pressure in the bladder has begun to be promoted. Studies on monitoring pressure in the urinary tract point to a high level of correlation with pressure in the abdominal cavity. These measures are currently conducted in the majority of workplaces by manual measurement in specified time intervals. In this article the verification of a monitoring system for measuring IAP is described, which is part of a proposed system for automatisisation of IAP detection.*

*Keywords: intra-abdominal pressure; measurement; sensors*

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## 1 Reasons for the Origin of IAH

The reasons for the origin of inter-abdominal hypertension can be divided into a number of groups based on the aetiology of origin:

1. post-traumatic – the reason for origin is a traumatic mechanism with subsequent damage to individual organs: massive multi-organ disabling, burning, intra-abdominal or retroperitoneal bleeding (a traumatic rupture of the aorta, bleeding from the spleen), massive contusion of the body (anti-shock trousers), swelling of tissues after a massive intake of fluids during resuscitation, [12]

2. on the basis of disease and disease complications – infection of the abdominal cavity (stercoraceous or biliary peritonitis), a place of abscess, acute pancreatitis, decompensation cirrhosis with ascites, edema and ascites after a massive intake of fluids, hemoperitoneum or hemoretroperitoneum, [12]
3. as a response to therapeutic procedures – peritoneal dialysis, artificial lung ventilation [12]
4. surgical procedures and their complications – laparoscopic surgery with enforced creation of pneumoperitonea, a large stomach operation, diaphragmatic hernia, application of an abdominal belt after an operation, post-operative bleeding, closing of the abdominal wall caused by pulling, oedema after a major operation (oncological operations). Acute post-operative dilation of the stomach; this is possible also after undergoing a gastrofibroscopic examination. [12]

Massive influx of fluids with forced volume therapy works on the abdominal wall in several ways. It leads to dilation of the veins in the area of the abdominal wall, becoming an oedema of the intestinal walls with increased pressure on the venous and lymphatic system with a resultant worsening of drainage. The stagnation of fluids in the intestinal wall endures with the development of tissue hypoxia. A vicious cycle begins; blood gets into the intestinal wall but does not reach the drainage of the venous system; the oedema grows. A decline in kidney function follows. According to recent studies close monitoring of the inflow and outflow of fluids is appropriate. [6, 7, 12]

## **2 Treatment of ACS**

In clinical practice we have been coming across occurrences of ACS for a long time, and history has recorded data in which increased IAP in critically ill patients leads to a growth in morbidity and mortality. [1, 2, 5, 7]

At present the occurrence of ACS is connected with repeated use of an old-new conception of treatment of serious traumatic injuries. In this strategy of treatment algorithm, a multi-stage procedure, described by different authors as Staged Laparotomy (Morris,1993), Planned Reoperation (Hisrhberg,1994), Abbreviated Laparotomy (Brenneman,1994) and Damage Control Laparotomy (Ivatury, 1997), is again fully acceptable. [1, 2, 12]

The essence of this approach is the carrying out of an immediate introductory laparotomy with necessary treatment of the organs and by stopping the life-endangering bleeding. The aim is to anticipate the origin of irreversible coagulopathy, because coagulopathy worsened by hypothermia and acidosis is considered as a primary factor in the timely death of patients after a serious abdominal injury. [12]

### 3 Verification of Measuring System

The testing device for verifying the pressure sensor consists of two parts (Fig. 3). In the first a model of the abdomen is made from a 250 ml saline bag (in the place of the bladder). This saline bag is placed in the bottom of a 35L container which allows pressure to be built up to 25 mmHg. Velcro is used to anchor the bag to the bottom of the container. [8, 10]

For determining the impact of the anchoring of the model of the bladder two versions of the clamp were tested. In the first version, the bag for the saline was anchored with two Velcro fastener strips along its full length in the middle. Upon testing it was determined that the edges of the bag have a tendency to lift and thus shift the zero point for measurement. To prevent such lifting of the bag edges, Velcro strips were attached to the inside of the container and to the four corners of the bag (Figure 4). [8, 10, 11]

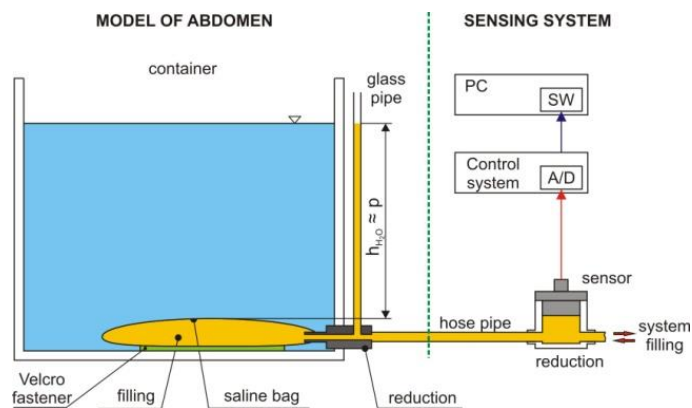


Figure 3

Schematic representation of sensing system [8, 10]

The second part is the sensing system.

The selection of an inter-abdominal pressure sensor is subject to strict hygienic and safety conditions. Among the most basic are that it be possible to disinfect the sensor and that upon its being damaged no contamination of the measuring space can occur. [8, 10, 11]

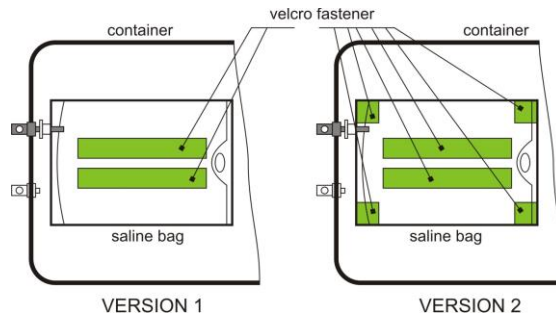


Figure 4  
Versions of the clamp

On the basis of the given criteria the selected sensor was model number DMP 331 P from the company BD SENSORS. The sensor is also supplied in a variant filled with edible oil. The basic parameters of the sensor are presented in Table 2. [8]

The measuring range (0-0.1) bar corresponds to 10 kPa or 75 mmHg, while 3.3 kPa or 25 mmHg is desirable. The sensor, therefore, has sufficient reserve for measuring. The sensor has an output of (0 – 5) V, thus it is possible to connect it directly into the microcontroller. [8]

Table 2  
Basic parameter of DMP 331 P sensor [8]

	Value
Measuring range [bar]	0 – 0,1
Accuracy	0,5% from measuring range
Output [V]	0-5
Cover	IP 65
Material of the sensor body	stainless steel
Filling	edible oil

The sensing system is connected to a reduction through tubing of 4mm inner diameter [10].

The measurement was performed as follows:

- the saline bag was filled with 100 ml of water
- 5 mmHg pressure was created through the water column, and the value was read from the level gauge,
- stabilization of the water level (15 - 20) s,
- measuring process (Figure 5),
- increasing the pressure up to 25 mmHg stepwise by 5 mmHg per step, measuring after each increment,

- decreasing the pressure after reaching 25 mmHg stepwise by 5 mmHg steps, measuring after each decrement,
- 20 measurement packs were obtained with this approach, and each pack contained 5 levels of measurement (5 – 25 mmHg with 5 mmHg steps) (Figure 5) (Table 3) (Table 4) [9, 10].

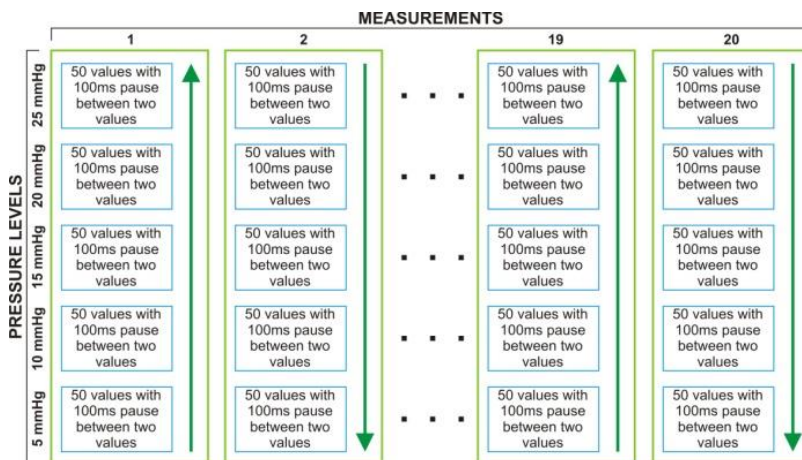


Figure 5

Schematic representation of measuring process [9, 10]

Each measurement contains 50 values with 100 ms pause between two values. The pressure sensor has an analog output (0 – 5V), which is processed in a PIC microprocessor. The program in the PIC was designed to read data from the sensor, perform the A/D conversion (10-bit) and then send the data to a PC. [8, 10]

The outcome consists of data in a range from 0 to 1023, which represents the total range of the sensor (0 – 75) mmHg or (0 – 0.1) bar. These are subsequently converted to a pressure value through the relation [8]

$$p_{BD} = \text{measured\_value} \cdot \frac{75}{1023} [\text{mmHg}]$$

The surface tension of the water in the container is reduced by adding washing up liquid, which allows for a more exact filling of the container to the desired level. [8, 10]

Table 3  
Table of the recalculated pressure values for version 1 [8, 10]

i	Pressure [mmHg]				
	$p(5)_i$	$p(10)_i$	$p(15)_i$	$p(20)_i$	$p(25)_i$
1	5,413	10,326	15,180	20,084	24,889
2	5,368	10,194	15,072	19,870	24,834
3	5,408	10,267	15,154	19,950	24,845
4	5,377	10,232	15,113	19,978	24,821
5	5,411	10,284	15,157	20,001	24,840
6	5,430	10,249	15,114	19,944	24,886
7	5,430	10,273	15,255	19,985	24,817
8	5,403	10,214	15,075	19,911	24,837
9	5,368	10,267	15,075	19,933	24,817
10	5,443	10,236	15,092	19,762	24,824
11	5,422	10,271	15,114	19,982	24,804
12	5,421	10,226	15,041	19,889	24,839
13	5,361	10,227	15,095	19,960	24,786
14	5,371	10,254	15,051	19,905	24,826
15	5,431	10,249	15,063	19,971	24,783
16	5,491	10,309	15,097	19,997	24,905
17	5,504	10,352	15,166	20,006	24,853
18	5,415	10,283	15,107	20,026	24,865
19	5,472	10,279	15,157	20,015	24,837
20	5,443	10,315	15,135	20,006	24,861
Mean $\bar{p}$	5,419	10,265	15,116	19,959	24,838
Standard deviation $s_p$	0,040	0,040	0,052	0,069	0,032
$\bar{p} + 3s_p$	5,538	10,384	15,270	20,166	24,934
$\bar{p} - 3s_p$	5,300	10,146	14,961	19,752	24,743

The values from the A/D converter are recalculated to a pressure value (Table 3, Figure 6). Data evaluation was performed in Microsoft Excel 2003. [8, 10]

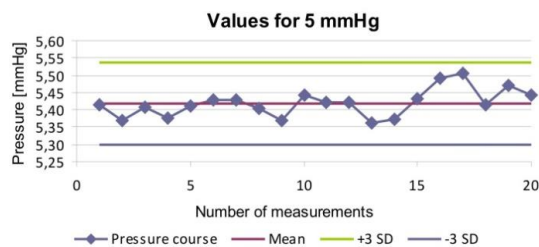


Figure 6

Trend for 5 mmHg, SD – standard deviation [8, 10]

The dependency of the measured values on the expected values is linear (Fig. 7), with a correlation coefficient from 0.98 to 1. [8, 10]

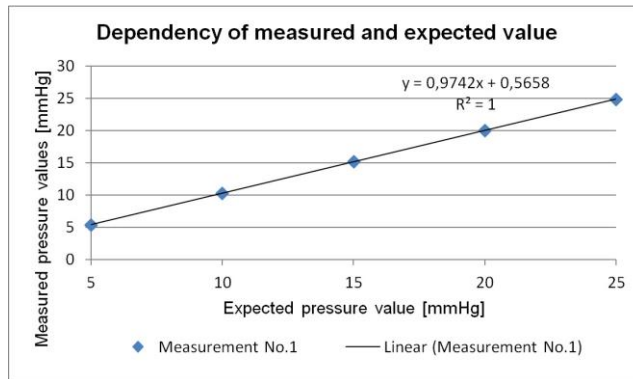


Figure 7

Dependency of the measured values on the expected values

Differences in the measured values upon comparison of both variants for solving the anchoring of the bag of saline solution are greater than 0.5 mmHg for each range. (Table 4, Table 5)

Table 4

Table of the recalculated pressure values for version 2 [8, 10]

i	Pressure [mmHg]				
	$p(5)_i$	$p(10)_i$	$p(15)_i$	$p(20)_i$	$p(25)_i$
1	4,799	9,713	14,472	19,274	24,258
2	4,799	9,809	14,414	19,403	23,965
3	4,826	9,638	14,367	19,346	23,978
4	4,821	9,701	14,522	19,518	23,993
5	4,771	9,463	14,430	19,304	24,000
6	4,786	9,691	14,589	19,424	23,930
7	4,837	9,521	14,422	19,334	23,936
8	4,805	9,691	14,518	19,397	24,006
9	4,779	9,641	14,434	19,333	24,021
10	4,779	9,645	14,469	19,384	23,877
11	4,757	9,570	14,346	19,264	23,874
12	4,736	9,658	14,431	19,204	23,963
13	4,691	9,567	14,447	19,315	23,930
14	4,716	9,638	14,427	19,367	24,028
15	4,701	9,644	14,458	19,321	24,019
16	4,680	9,560	14,446	19,292	23,977
17	4,685	9,685	14,475	19,296	23,950

18	4,676	9,616	14,378	19,219	23,897
19	4,691	9,543	14,386	19,267	23,908
20	4,692	9,632	14,302	19,368	23,924
Average $\bar{p}$	4,751	9,631	14,437	19,332	23,972
Standard deviation $s_p$	0,055	0,078	0,065	0,074	0,082
$\bar{p} + 3s_p$	4,918	9,865	14,631	19,553	24,218
$\bar{p} - 3s_p$	4,585	9,397	14,242	19,110	23,725

The following table (Table 5), which determines the difference of a nominal (reference) value versus a measured value, serves for determining the better variant.

Table 5  
Pressure differences between two variants

i	Pressure [mmHg]				
	$p(5)_i$	$p(10)_i$	$p(15)_i$	$p(20)_i$	$p(25)_i$
1	0,6139	0,6134	0,7079	0,8098	0,6309
2	0,5689	0,3846	0,6585	0,4668	0,8692
3	0,5825	0,6292	0,7874	0,604	0,867
4	0,5559	0,5311	0,591	0,4604	0,8283
5	0,6397	0,8207	0,7274	0,6975	0,84
6	0,6441	0,5584	0,5246	0,5202	0,9564
7	0,5928	0,7525	0,8327	0,6507	0,8815
8	0,598	0,5234	0,5574	0,5136	0,8311
9	0,5894	0,6262	0,641	0,6002	0,7965
10	0,6644	0,5908	0,6228	0,3778	0,9472
11	0,6654	0,7006	0,768	0,7181	0,9301
12	0,6849	0,5676	0,6099	0,6852	0,8757
13	0,6704	0,6596	0,6478	0,6448	0,8564
14	0,6555	0,6162	0,6243	0,5384	0,7981
15	0,7301	0,6053	0,6055	0,6499	0,7639
16	0,8106	0,7489	0,6513	0,7052	0,9285
17	0,8192	0,6672	0,6909	0,7098	0,9029
18	0,739	0,6672	0,7287	0,8075	0,9676
19	0,7814	0,7365	0,7714	0,7481	0,9294
20	0,7509	0,683	0,8329	0,638	0,9372
Mean	0,6678	0,6341	0,6790	0,627	0,86689
Standard deviation $s_p$	0,0804	0,0975	0,0881	0,1171	0,0803

The individual values are calculated as follows:

*Deviation I* = Absolute value (nominal value – value of “version I”).



Total deviation for the selected version = the sum of all deviations for selected version. (Table 6), (Figure 8)

Table 6  
Calculation of differences between two variants

Nominal Value	Version 1	Version 2	Deviation 1	Deviation 2
5	5,419	4,751	0,419	0,249
10	10,265	9,631	0,265	0,369
15	15,116	14,437	0,116	0,563
20	19,959	19,332	0,041	0,669
25	24,838	23,972	0,162	1,028
Total deviation			1,003	2,8779

From the results it is obvious that the total deviation for Variant 2 is nearly 3-times the total deviation for Variant 1. From this it follows that anchoring the bag of saline solution using Variant 1 is more suitable.

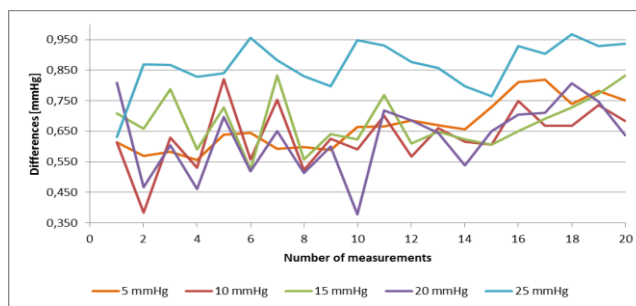


Figure 8  
Values for differences between two variants

### 3.1 Measurement Error Determination

The total error measurement is given by the error of the sensor and the error of the converter.

The error of the sensor is given by the manufacturer and represents 0.5% of the measuring range, which is, to the extent required, a precision of measuring to a whole number; the sensor also satisfies this condition. [8]

$$\varepsilon_s = \frac{\text{sensor\_range}}{100} \cdot \text{sensor\_error} = \frac{10000 \text{ Pa}}{100} \cdot 0,5 = 50 \text{ Pa} \quad \text{resp.} \quad 0,375 \text{ mmHg}$$

For digitalisation of the pressure from the sensor, an integrated 10-bit converter is used. [8]

The sensitivity of the converter *LSB* (Least Significant Bit) can be calculated from the relation:

$$LSB = \frac{FS}{2^n} = \frac{5V}{2^{10}} = 0,00488V$$

where *FS* (Full Scale) is the range of the converter and *n* is the number of bits.

A quantization error represents the theoretical maximum difference between the value of the analogue parameter and its maximum value corresponding to the given code word; it is given by the relation:

$$QE = \frac{LSB}{2} = \frac{0,00488V}{2} = 0,00244V$$

The accuracy of the pressure measurement for a measuring a range of 0.1 bar, i.e. 75 tors, can be calculated from the relation:

$$\frac{LSB}{FS} \cdot sensor\_range = \frac{0,00488V}{5V} \cdot 75\text{mmHg} = 0,0732\text{mmHg}$$

If a sensor error reaches the maximum allowable value and at the same time a quantization error is also expressed, then there is a total error of measurement:

$$\begin{aligned} \varepsilon &= \varepsilon_s + \varepsilon_p = \varepsilon_s + \frac{QE}{FS} \cdot sensor\_range = \\ &= 0,375\text{mmHg} + \frac{0,00244V}{5V} \cdot 75\text{mmHg} = 0,41\text{mmHg} \quad \text{resp.} \quad 54,66\text{Pa} \end{aligned}$$

Because intra-abdominal pressure is measured for an entire unit, this error is below the margin of acceptability. Its value can be lowered by use of a converter with higher resolution capability. The total error of measurement for a 16-bit converter is on the level of the sensor error. [8]

$$\begin{aligned} \varepsilon &= \varepsilon_s + \varepsilon_p = \varepsilon_s + \frac{1}{2} \frac{FS}{2^n} \cdot sensor\_range = \\ &= 0,375\text{mmHg} + \frac{1}{2} \frac{5V}{2^{16}} \cdot 75\text{mmHg} = 0,376\text{mmHg} \quad \text{resp.} \quad 50,13\text{Pa} \end{aligned}$$

## Conclusion

A proposed measuring device for medical applications must satisfy the appropriate conditions for safety and for reliable use. The sterilisation of all parts which come into contact with body fluids (urine) is one of these conditions. This condition has a basic effect during sensor selection.

In the course of testing the system's sensor two methods of anchoring the bag for saline solution were verified. The methodology for testing was the same in both cases. In view of the principles of the measurement (measuring with a column of water) it was necessary to measure under stable weather conditions, because a change in atmospheric pressure can influence the measured values. The difference between the two methods of anchoring for pressures of 5 – 20 mmHg is approximately 0.65 mmHg and for a range of 25 mmHg it is approximately 0.87 mmHg. Because when measuring internal-abdominal pressure measuring in units of mmHg is sufficient, the measuring of intra-abdominal pressure is within the tolerance limits for both Variants. From an evaluation of the results, it follows that measuring using Variant 1 is more precise.

The total error of the sensing system is on a level of 0.41 mmHg. For decreasing the total error of measurement it is possible to use a stand-alone 16-bit A/D converter. The total error in this case will be equal to the sensor error.

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