Features of the Data Transmission in the Wireless Capsule Endoscopic Complex

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Abstract
This article describes the features of the data transmission between a wireless endoscopic capsule and a reading device. The advantages and disadvantages of using a uni- and a bidirectional communication in the capsule are considered and the unidirectional communication is chosen as a preferred one. The various embodiments of the integrity control and the recovery are analyzed and experimentally verified. To justify the choice between the noiseless coding and the checksums we carried out an experiment on the effect of their implementation on energy consumption of the endoscopic capsule. It was found that the noiseless coding significantly reduced the battery life of the capsule and the choice was made in favor of the checksums.

Keywords: data transfer between the capsule and the reader, communication, radiofrequency protocol, communication implementation algorithms

1 Introduction

Wireless capsule endoscopy is a modern method of diagnosis of the digestive tract with the help of a tiny ingestible capsule with a built-in camera (Mikhaylov 2014a, Khabibullin 2015, Mitselos 2015). The capsule passes through the gastro-intestinal tract (GIT) tacking the images of the inner walls and transmits the data to the reader; then the images are processed on a computer using special software recognizing the diseases (Mikhaylov 2014b).

This diagnostic area is promising, the research and development to improve the technical performance of the capsule endoscopic systems are maintained in different directions: improving the software (Mikhaylov 2014a, Mikhaylov 2014b, Kukushkin 2012), the capsule control (Mikhaylov 2014c, Mikhaylov 2015), the lighting, the transmitter/receiver elements (Mikhaylov 2014c), etc.

The issue of the data exchange between the capsule and the reader is particularly relevant, since their completeness influence among other the diagnosis correctness. This is discussed in many scientific articles, for example, Ding et al. (2015) present a wireless power transfer and bidirectional data communication system for capsule endoscopy. Carta and Puers (2011) propose a wireless power
and data transmission for a robotic capsule endoscope. In (Feng 2015) authors describe a Wi-Fi based transmission technology for wireless capsule endoscopy that potentially allow to use the common Android mobile phone or iPad as the endoscopic receiver.

The proposed solutions provide the communication between the capsule and the reader to transfer images, control commands, etc. However, they are often energy-consuming, which reduces the capsule operation time and has a negative impact on the examination results. There is also a likelihood of the substantial data loss.

This article describes the implementation of the data packets transfer for the developed capsule endoscopic complex Landish. This approach will take into account the existing shortcomings in the data transfer methods and will help to select the optimal solution for the endoscopic complex.

2 Communication Realization Algorithms

There are two possible algorithm of communication implementation between the capsule and the reader:

– on the basis of the unidirectional communication, when the endoscopic capsule has a radio transmitter, and a device receiving images obtained by the capsule – radio receiver;

– on the basis of the bidirectional communication, when the device receiving the images from the capsule may also send the configuration data on the capsule (set light-emitting diodes’ (LED) brightness, change resolution, etc.).

Note, that this is not the only option – the waiting configuration information by the capsule can take place parallel to the main work cycle consisting of exposition and image sending or between the sending of two images.

Table 1 shows the advantages and the disadvantages of these methods in relation to the developed wireless endoscopic capsule.

<table>
<thead>
<tr>
<th>Communication method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unidirectional</td>
<td>Does not require a doctor's decision on capsule settings before the procedure. Simplification of the antenna system.</td>
<td>No possibility to adjust the capsule operation for the target research area before the procedure.</td>
</tr>
<tr>
<td>Bidirectional</td>
<td>Allows to adjust the capsule to the target research area (to increase the resolution of the intestine or the speed for the esophagus and the stomach)</td>
<td>Requires a doctor to make a decision before the capsule swallowed. More complex algorithm of work. More complex antenna system.</td>
</tr>
</tbody>
</table>

Table 1: Advantages and disadvantages of uni- and bidirectional communication

Making a decision about the necessary settings before the procedure is trivial, but the ability to use an asymmetric antenna system (focused on the transfer, rather than on the reception) is a significant advantage. At the same time the advantages of the bidirectional communication are leveled by the functional requirements for providing the higher resolution and the data rate at the higher power consumption. Thus, at this stage it would be appropriate to use a unidirectional communication.

3 Features of Radio Frequency Protocol

Consider the features of the radio frequency protocol implementation in terms of reliability of packets delivery and monitoring of their correctness (integrity). Each radio channel can be characterized by the so-called Bit Error Rate (BER). This quantity is the probability of the error in a randomly selected bit. In fact, the bit error probability is uneven for different bits, however, through
the statistical experiment the average value is calculated. (Lim 2010) In general, BER is determined by
the signal level at the receiver, the transmitter and the receiver quality.

There are non-radiotechnical methods for improving BER characteristics: using of noiseless
coding (e.g., Reed-Solomon (Piterson 1976), which adds redundant bits but allows to recover the
original message in the case of a single or repeated (depending on the number of redundant bits) error.

Also, for tasks that are not data-loss critical but critical to their incorrectness we can used the
checksum – redundant bits calculated from a controlled set of bits ensuring that when an N-
multiplicity error occurs (presence of N incorrect bits, where N depends on the number of the
redundant bits and the algorithm used), the checksum recalculation will lead to a different result. Thus,
the data recovery will not be possible but the set of the received bits can be verified and discarded or
put into operation (with a certain probability the checksum of the correct and the incorrect control set
may coincide, however, the order of this probability can be estimated as BER\textsuperscript{N} that, for example, for
the CRC16 algorithm and BER that equals 10\textsuperscript{-4} is equal to 10\textsuperscript{-64}).

The last tool to provide the reliability of the communication is the use of the protocol with
confirmation when the transmitter ensures retransmission of the next set of bits when the receiver has
not confirmed it for some time.

It is possible to use the combinations of any two or all three methods creating the communication
system with different properties for different applications. The selection between the items can be
made only by an experiment.

The experiment provides a collection of statistical data on losses by using the methods above in
equal physical conditions (use of the same hardware, the spatial configuration of the antenna system)
with a change at the software level. The experiment was carried out, starting with the simplest
mechanism that does not use any of the methods of BER improving in the direction of complexity –
the use of the checksum, the use of the noiseless coding, and the combination of the noiseless coding
and the checksum.

The experiment was carried out according to the scheme is shown in Figure 1, the software
uploaded into the endoscopic capsule mockup was modified. The number of the incorrectly
transmitted images was calculated. The image was considered as an incorrect if the JPEG format was
broken that was determined automatically by the software. Since JPEG is a compressed image and has
a certain structure of storage, the inability of the correct processing of this structure can be regarded as
an indirect sign of an error in image transmission over the air. The transition from BER to the images
was carried out deliberately, because the images are the result of the system performance.

The first experiment involved the transfer of the images without using the checksum and noiseless coding
(Table 2). The second experiment involved the transmission of the images using the checksum, the
check of which allowed to discard the packets containing error (Table 2).

The results may seem inconsistent with the hypothesis that the probability of the packet loss while
using the checksum is higher than the probability of damage of a single bit without the checksum use.
However, there emerged another effect – without the checksum it was likely to receive the data from
the air (the source of which is not an endoscopic capsule). To confirm this hypothesis, we repeated an
experiment with the images transmission without the checksum in an anechoic chamber, the walls of
which absorb the external electromagnetic fields (Table 2).

This experiment confirmed the hypothesis of receiving the data from the air, which are discarded if
the checksum is applied. It also showed that the rejection of all control and recovery mechanisms
significantly reduced the electromagnetic compatible of the capsule (that degraded by several hundred

Figure 1: Scheme of the experiment to determine the optimal method to improve the reliability of the radio channel.
times one of the key indicators of its work – the probability of a successful image transmission) in a domestic environment – the presence in the air of Wi-Fi, Bluetooth signals and other sources at frequencies of 2.4-2.5 GHz is the condition of the environment in almost every city and place. Thus, the total rejection of the control and/or recovery mechanisms is unacceptable.

The third experiment involved the image transmission using the noiseless coding, which allowed to recover the packet in the case of a limited number of errors. The results are shown in Table 2.

The result can be interpreted as follows: despite the BER decline, which is predicted for the Reed-Solomon code and a packet length of 32 bytes at the level of the two orders, the percentage of the errors is comparable with the experiment, in which the checksum was used. This is a consequence of the presence of a small number of incorrect packets, in which there are a large number of incorrect bits. The experiment confirmed the assumption about the uneven distribution of the likelihood of the incorrect bits. In other words, the experiment showed if getting a single incorrect bit the probability of obtaining the second consecutive incorrect bits is significantly higher than BER2.

Thus, with other things being equal, it is preferable to use the Reed-Solomon code over the checksum, however the advantage is insignificant and requires to check other characteristics of the system that are affected by the use of the checksum or the Reed-Solomon code, in particular – the energy consumption, and as a consequence, the battery life of the capsule.

The final experiment was carried out using both the checksum and the noiseless coding (Table 2).

The result was consistent with the experiment in which only the noiseless coding was used. When the recovery was possible (in a few cases), it happened, so the result was slightly better than when using the checksum. However, the main source of the packet’s loss and, accordingly, the images are the large groups of invalid bits, which cannot be recovered. Adding the checksum to the noiseless coding has not changed the key indicator – the probability of the image loss.

<table>
<thead>
<tr>
<th>Experiment type</th>
<th>Total number of images</th>
<th>Number of incorrect images</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without control and recovery mechanisms</td>
<td>16500</td>
<td>75</td>
<td>0.45%</td>
</tr>
<tr>
<td></td>
<td>16600</td>
<td>28</td>
<td>0.17%</td>
</tr>
<tr>
<td></td>
<td>15600</td>
<td>48</td>
<td>0.31%</td>
</tr>
<tr>
<td></td>
<td>16100</td>
<td>56</td>
<td>0.35%</td>
</tr>
<tr>
<td>Using the checksum</td>
<td>15660</td>
<td>2</td>
<td>0.01%</td>
</tr>
<tr>
<td></td>
<td>15656</td>
<td>6</td>
<td>0.03%</td>
</tr>
<tr>
<td></td>
<td>15685</td>
<td>3</td>
<td>0.02%</td>
</tr>
<tr>
<td></td>
<td>16381</td>
<td>9</td>
<td>0.06%</td>
</tr>
<tr>
<td>Without control and recovery mechanisms in an anechoic chamber</td>
<td>16660</td>
<td>1</td>
<td>0.0006%</td>
</tr>
<tr>
<td></td>
<td>16754</td>
<td>1</td>
<td>0.0005%</td>
</tr>
<tr>
<td></td>
<td>15985</td>
<td>2</td>
<td>0.001%</td>
</tr>
<tr>
<td></td>
<td>16240</td>
<td>1</td>
<td>0.0007%</td>
</tr>
<tr>
<td>Using the Reed-Solomon noiseless coding</td>
<td>16260</td>
<td>4</td>
<td>0.02%</td>
</tr>
<tr>
<td></td>
<td>16114</td>
<td>3</td>
<td>0.02%</td>
</tr>
<tr>
<td></td>
<td>15892</td>
<td>3</td>
<td>0.02%</td>
</tr>
<tr>
<td></td>
<td>15986</td>
<td>3</td>
<td>0.02%</td>
</tr>
<tr>
<td>Using the noiseless coding and the checksum</td>
<td>16182</td>
<td>3</td>
<td>0.02%</td>
</tr>
<tr>
<td></td>
<td>16410</td>
<td>3</td>
<td>0.02%</td>
</tr>
<tr>
<td></td>
<td>16323</td>
<td>3</td>
<td>0.02%</td>
</tr>
<tr>
<td></td>
<td>15984</td>
<td>3</td>
<td>0.02%</td>
</tr>
</tbody>
</table>

Table 2: Results of the experiments

Now, to select between the noiseless coding and the checksum, compare the consumption of the endoscopic capsule mockup. Since the checksum is implemented strictly at the transmitter crystal and the noiseless coding is programmed, it is energetically more efficient to use the checksum. To confirm
this hypothesis and determine the influence of the noiseless coding on the capsule life time, let us carry out an experiment, which scheme is shown in Figure 2.

The first experiment shows a graph of the endoscopic capsule consumption when using the checksum at different levels of the supply voltage (simulating low battery) and the second – when using the noiseless coding (Figure 3).

It is clear from the graphs that the excess energy when using the noiseless coding is 5mA during the data transfer (the second "step" in the chart). The average value of the excess is about 2mA. Taking into account the average consumption of the capsule of 16mA, the excess is 12.5%, which, respectively, reduces the endoscopic capsule battery life by 12.5%. Given the small difference in the number of unrecognizable images it is proposed to use the checksum only.

4 Conclusion

Thus, for the developed wireless capsule and the reader of the capsule endoscopic complex "Landish" we identified the features for the implementation of the data transfer process. A valid choice in favor of the unidirectional communication without a wireless capsule configuration was made.

It has been experimentally shown that the non-use of any control mechanisms significantly increases the percentage of "broken" images due to the lack of any software methods of suppression of the high electromagnetic sensitivity of the radio receiving circuit, while the difference between the use of the noiseless coding and the checksums was insignificant (in favor of the noiseless coding ). It was found that the noiseless coding significantly reduces the wireless capsule battery life and the choice was made in favor of the use of the checksums.

In the future it is planned to conduct the testing and the debugging of the data transmission system between the endoscopic capsule and the reader with the selected in the article approaches. It is expected that the system will have low power consumption and will not yield to the analogues on the efficiency and the quality of image transmission.

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