Analog-to-digital data processing tools in the construction industry and in the transportation sector

A I Konikov and T A Fedoseeva

1Moscow State University of Civil Engineering (MGSU) National Research University, 26, Yaroslavskoye sh., 129337, Moscow, Russia

E-mail: FedoseevaTA@mgsu.ru

Abstract. In many applications in the construction industry and in the transportation sector, it is necessary to convert the original analog information into digital form and transmit this information for further computer processing using the appropriate interface. The question of the correct choice of conversion means (analog-to-digital converters, ADC) and transmission means (interfaces of peripheral devices) is very important because the characteristics of these devices largely determine the quality of the system. Meanwhile, in this area there is a fairly wide range of modern solutions, new trends are observed, which should be taken into account by system developers. Often systems are operated in conditions of high levels of industrial noise and interference. In a number of applications, it is required to process the signals of sensors (for example, building condition sensors) with very high accuracy with moderate processing speed requirements. The choice of a solution is significantly affected by the fact that modern building condition monitoring systems, automated control systems for technical processes in construction, and other systems are built on the basis of microcontrollers. In this study, the above issues are considered comprehensively, on the basis of this, possible solutions are proposed, practical recommendations are given.

1. Introduction

The paper explores issues related to the rational choice of the ADC and the corresponding interface for data processing systems in the construction industry and in the transportation sector. This topic has become especially relevant in connection with the advent of new technologies: Big Data [1-9] (allows you to process the signals of numerous sensors); Digital double [10] (allows improving the quality of construction due to the use in the digital model of information received from sensors installed on the building) and others.

2. Materials and methods

First, consider the problem of choosing an ADC. Systems used in the construction industry and in the transportation sector require three types of converters.

I. Flash ADC (direct-conversion ADC, parallel -type ADC)

ADC capable of operating at a frequency of several gigabit per second (giga samples per second). Such speeds are required when processing signals arriving on broadband communication lines, for example, some solutions used in smart home technologies. It is known that the highest conversion speed is provided by the flash ADC. In such converters, the input signal U is simultaneously fed to the first inputs of the comparators (Figure 1).
The reference levels are fed to the second inputs of the comparators. The entire range of the input signal $U_{\text{min}} - U_{\text{max}}$ is divided into $2^n$ equal intervals $\Delta$, where $n$ is the number of bits of the ADC.

Thus, the magnitude of the quantum and, accordingly, the accuracy of the conversion are determined by the number of bits $n$. On the other hand, the number of comparators depends on the value of $n$ in the proportion $2^n$. In many applications where fast signal processing is used, the tradeoff is $n = 8$. Indeed, with $n = 8$, an accuracy of $\sim 0.5\%$ is achieved, for most of the applications under consideration this is quite enough. Increasing the accuracy to 9 or 10 digits will require increasing the number of comparators to 511 and 1023 (in the general case, $2^n - 1$). Given that the comparator is an analog device, with all the disadvantages inherent in this type of device (temperature and time parameter drifts, etc.), such an increase is undesirable. For example, if the ADC is part of the microcontroller, then an increase in the number of comparators either leads to an increase in cost or “takes” part of the resources from other components of the microcontroller. Sometimes you can restrict yourself to less accuracy $n < 8$, then you can choose a more economical or more functional microcontroller. In any case, the number of bits of the ADC should be selected from the system requirements, based on considerations of "reasonable sufficiency". In particular, the level of interference at the input of the ADC should be considered. If the level of these noises is comparable or exceeds the value of $\Delta$, then it is reasonable to reduce the number $n$, since the least significant bits of the ADC will essentially digitize the noise.

II. Successive approximation ADC.

![Figure 1. A flash ADC.](image)

![Figure 2. A ADC of successive approximations.](image)
The best combination of speed, accuracy and the volume of equipment provides an ADC of successive approximations (Figure 2). The work of this ADC is based on the binary (binary) search method, well known in mathematics.

The work is based on a sequential comparison of the input voltage \( U \) and the value of the composite deterministic signal \( U_d \). At each of \( n \) steps, the difference \( \varepsilon = U - U_d \) decreases by half and the next bit of the output code is formed. In the last \( n \) step, condition (2) is satisfied

\[
\varepsilon < \Delta
\]

Thus, the ADC converts the input quantity \( U \) into an \( n \)-bit code accurate to a quantum.

The voltage \( U \) is applied to the first input of the comparator, and the composite deterministic signal \( U_d \) formed by the digital-to-analog converter is supplied to the second input. Depending on the result of the comparison, the corresponding bit is generated in the \( n \)-bit code. A characteristic feature of this ADC is that the volume of equipment is almost independent of the number of output discharges.

When choosing the characteristics of the ADC of successive approximations, the system requirements should be considered. Here the rule stated earlier applies: the number of bits \( n \) should be taken so that the noise level does not exceed the value of the quantum \( \Delta \) (otherwise the lower bits of the code will be unreliable).

In addition, to use the ADC of successive approximations, one more condition is necessary: the change in the input quantity \( U \) during the conversion time should be less than \( \Delta \). If this condition is not met, then the process of successive approximations may not converge and relation (2) will not be fulfilled. In other words, the conversion error can significantly exceed the value of quantum \( \Delta \). In practice, the following solution is used as an output. A sample and hold circuit is installed at the ADC input, which maintains a constant signal value during analog-to-digital conversion.

Due to the optimal combination of basic characteristics, the serial approximation converter is the most common type of ADC and is often used in computer systems of the construction industry and in the transportation sector. These ADCs are in demand in systems for computer monitoring the state of a building, in automation systems for building processes, in smart home solutions and other applications where very high performance is not required (flash ADCs are used here, see above) or very high accuracy (used sigma -delta ADC, see below). ADC of successive approximations is a part of many microcontrollers MC. Sometimes the type of ADC is not indicated in the technical documentation - then most often the ADC of successive approximations is meant (note that often the type of ADC can be “calculated” by the characteristics of the converter).

III. Sigma - delta ADC

In cases where it is necessary to obtain very high accuracy (of the order of 20 bits and higher) with very moderate performance requirements, ADCs built on the principle of “signal integration” are used. Indeed, the integration of the signal can significantly compensate for noise and interference and to obtain high conversion accuracy. The “classic” integrating type of the ADC works very simply: within a fixed time \( T_0 \), the integrator is charged to a certain level under the influence of the input voltage \( U \), during the time \( T_1 \) the integrator is discharged to zero using a reference signal of opposite polarity. The ratio of time \( T_0 \) and \( T_1 \) determine the output code. Such ADCs are used (infrequently) in measuring devices (digital voltmeters).

Thus, integrating ADCs in the “classic” version for computer systems in the construction industry and in the transportation sector are not of great interest. But in these systems the so-called sigma -delta ADCs are often used. In the process of converting such ADC, a number of methods are used, an important place is occupied by the signal integration method. These ADCs are used for precision pressure, temperature, weight sensors and any other applications where high demands are placed on accuracy and stability of conversion. In modern devices, the number of discharges reach values of 22 - 24 and this is not the limit. Converters of this type can be effectively used in many computer systems...
of the construction industry, in particular when monitoring the condition of construction objects in the transportation sector.

Let us now consider the second category of devices - peripheral device interfaces (in the context of their use in automated systems of the construction industry and in the transportation sector).

For methodological reasons, it is advisable to divide interfaces into groups. The first group includes high-speed interfaces with a small range. Let's start with the well-known USB interface. First of all, we note that this interface reflects a general trend in the field of modern interfaces - the transition from synchronous parallel interfaces to high-frequency serial ones. Indeed, the signal transmission in the USB 2 interface is carried out sequentially with the help of a twisted pair cable, in subsequent modifications of the USB the number of twisted pairs is increased. As a result, transmission speeds of up to 20 Gbit / s are achieved (it is clear that this is not the limit). Recall that the interface has several advantages: it provides power to peripheral devices, allows you to connect a large number of devices to one connector, etc. The main disadvantage is the small radius of action (typical value - 5 m.).

In the segment of high-speed interfaces, USB has virtually crowded out the IEEE 1394 (FireWire) interface. This interface is used relatively rarely: in audio, video, and some other applications that are not specific in the transportation sector.

Next, consider a group consisting of two SPI and I²C interfaces. The choice of these interfaces is due to the fact that they are part of many devices (ADCs, sensors, microcontrollers, etc.), on the basis of which automated systems are created. In the list of devices, the position “microcontroller” is especially important, since the presence of an interface in the controller significantly expands the scope of its use.

Consider the SPI interface - a serial data transfer interface. Its main purpose is to provide a simple and inexpensive high-speed interface for microcontrollers and peripherals. The term “high-speed interface” should be clarified. This means that the SPI throughput is higher than that of other interfaces in this segment, in particular I²C. This is achieved due to the fact that SPI contains a separate bus for device selection (no need to transmit the address of the desired device bit by bit). This advantage is achieved a high price - the SPI interface includes 4 wires (and not 2, such as I²C), which is a lot for a serial interface, especially when transmitting over long distances. In this regard, we note that the SPI interface is significantly inferior in terms of transmission distance to the RS-485 and CAN interfaces (see below). The SPI interface has other disadvantages, in particular there is no acknowledgment signal. These shortcomings significantly narrow the scope of the interface. However, SPI is possible for two reasons. First, in specific systems, the advantages of an interface can outweigh the disadvantages. Secondly, SPI is part of many hardware (in particular microcontrollers), there is experience with this interface.

Briefly consider the I²C interface. There are no disadvantages inherent in SPI in the I²C interface - only two conductors are used to connect many devices, there is a confirmation signal. The price for this is a reduction in speed, so I²C is mainly used to connect low-speed peripheral components to processors and microcontrollers. There are a number of additional advantages (“hot” connection, built-in filter, etc.) and disadvantages (limitation on line capacity - 400 pF, etc.).

Consider the category of interfaces with a large radius of action - we are talking about RS 485 and CAN interfaces. The following situation is typical for automated systems of the construction industry:
it is necessary to process signals from sensors located at a great distance with a high level of industrial noise and interference. In this case, the RS 485 and CAN interfaces are the most promising.

Both of these interfaces use a differential signal for transmission: the same electrical signal is transmitted in the form of two signals, one represents the inverted signal of the other (opposite in sign). In both interfaces, a pair of conductors is implemented as a twisted pair. A differential signal receiver responds to the difference between two signals, and not to the difference between one wire and ground potential (this transmission method is called asymmetric). The differential transmission method has several advantages. One of them is high noise immunity. Indeed, if the signal was affected by external noise, then, with a differential transmission method, this will not affect the result - since the receiver responds to the difference of the signals (Figure 3.)

![Figure 3. Noise does not affect the signal.](image)

Another feature inherent to both CAN and RS 485 is failure protection. This is necessary to protect devices from accidental short circuits between the power source and transmission lines.

A few words separately about each interface. The CAN interface has a number of interesting solutions. To abstract from the transmission medium, the CAN specification avoids describing data bits as “0” and “1”. Instead, the terms “recessive” bit and “dominant” bit are used, and when one node of the network transmits a recessive bit and the other transmits a dominant, a dominant bit will be accepted. This approach has proven effective in complex systems with many nodes and possible collisions. In the CAN interface, transmission is in frames. The useful information in the frame consists of an identifier and a data field. The identifier talks about the contents of the packet and serves to determine the priority when trying to transmit multiple network nodes simultaneously.

The CAN interface provides access arbitration. Since any node can start transmission at any time, simultaneous transmission of frames by two or more nodes is possible. When a message with a higher priority is transmitted, transmission of a lower priority is delayed until the bus is released. Thus, in CAN there is no decrease in throughput in the event of collisions.

To increase transmission reliability, a number of tricks are used in the CAN interface. Some of them are well known - using a checksum. Others are less well-known: for example, the “complementary bits” method - after transmitting five identical bits in a row, a bit of the opposite value is automatically transmitted. The indicated measures to increase reliability, on the one hand, reduced the transmission speed, and on the other, increased the range. In this case, the usual pattern in the field of communication is observed: the speed is directly related to the range - at a range of 40 m, the speed is 1 Mbit / s, at 5000 m - 10 Kbit / s.

Now briefly dwell on the features of the RS-485 interface. This standard governs the electrical parameters of a half-duplex multipoint differential link. There are a number of reasons why one should pay attention to this standard:

1. The standard has gained great popularity and became the basis for creating a whole family of industrial networks widely used in industrial automation, in particular in the construction industry.

2. The standard has serious advantages: simplicity (relative to the CAN), good noise immunity (due to the use of differential mode), good range (up to 1200 m).
3. In many cases, the standard is suitable for users, they have the appropriate equipment, experience with RS-485 and need good reason to change this interface to another (for example, CAN).

In general, it can be said that in point-to-point systems requiring a high data rate, the RS 485 interface is preferable due to a simple frame and higher speed. In complex systems with many nodes and possible collisions and at speeds <1 Mbit / s, CAN has the advantage. This is especially true for systems operating in a wide range of operating temperatures and at a high level of external influences.

When developing new automated systems for the construction industry, you should “track” solutions that are designed for other purposes, but have attractive technical characteristics. (Note that the CAN interface was initially intended to control the electrical devices of the car). So, the LVDS interface is of interest - it is built on the use of a differential signal transmission method, it combines high speed and low energy dissipation.

3. Conclusions

When designing computer systems for collecting and processing data, control systems for technical processes, etc. an important role is played by devices for digitizing initial analog information (ADC) and devices for delivering this information to a computing device (interfaces). The paper studies the issues of rational choice of the ADC and the corresponding interface for computer systems in the construction industry and in the transportation sector.

It is shown that in the ADC class 3 types of devices are in demand:

- A flash ADC (also known as a direct conversion ADC, a parallel ADC) - allows you to work in high-frequency applications (usually in the range of several GHz). Such speeds are required when processing signals arriving on broadband communication lines in a number of solutions used in smart home technologies. Recommendations are given for a rational choice of the number of bits n of such ADC. It is shown that a more economical two-stage option is not practical to use, since performance is greatly reduced.

- A successive approximations ADC - provide the best combination of parameters: accuracy - speed - volume of equipment. They occupy the main segment of devices of this type. Such ADCs are used in the processing of signals from building condition sensors, in automation systems of building processes, in smart home solutions and other applications where very high performance or exceptional accuracy are not required. The problems that arise when using such ADCs are considered, methods for solving them are indicated.

- A sigma-delta ADC. It is shown that in cases where it is necessary to obtain very high accuracy (on the order of 22-24 bits) at a very moderate timing requirements apply ADC, built on the principle of "integration of signal". It is noted that the "classic" type of an integrating ADCs for the construction industry is not of interest. There are good prospects for the sigma-delta ADC that use the "signal integration" method during conversion. These ADC are used for precision sensors for pressure, temperature, weight, etc. (in particular, for computer monitoring of the state of construction objects).

In the “interfaces” section, three groups of devices are investigated:

- Fast interfaces, calculated not a small transmission distance. Of the two representatives of this class – USB and IEEE 1394, for construction applications recommended well-known USB interface. The reasons for this choice are substantiated, a number of recommendations on the use of this interface are given.

- A group of interfaces, including SPI and I²C - are part of many microcontrollers, have fewer wires (than USB), but more modest indicators in terms of transmission speed. It is noted that the SPI interface has a higher transmission speed (than I²C), however, there are a number of fundamental disadvantages - 4 transmission lines (I²C interface has two). There is no acknowledgment signal in the interface (that is, the transmission can be conducted to “nowhere”). There are other disadvantages that limit the scope of this interface.

There are no disadvantages inherent in SPI in the I²C interface - only two conductors are used, there is a confirmation signal. However, in this case, the address of the selected device must be transmitted sequentially, bit by bit, as a result, the transmission speed is lower than that of SPI. The
advantages and disadvantages of the interface are analyzed, the conclusion is made: the I²C interface can be considered as a working option in the design of automated systems in construction.

In the third group, interfaces are studied that can work at large distances (1000 m and above), with a high level of industrial noise and interference. In particular, to process the signals of the sensors located at a considerable distance. It is indicated that in this case the RS 485 and CAN interfaces are the most promising. Both interfaces are built on a differential signal transmission method, which has several advantages - in particular, high resistance to external interference. The noise suppression mechanism in the differential transmission method is investigated. The advantages and disadvantages of each of the two interfaces are analyzed. It is shown that in systems requiring a high data exchange rate, due to the higher speed and simple frame, the RS 485 interface is preferable. CAN has advantages in multi-node systems with collisions and transmission speeds of less than 1 Mbps. This advantage is especially evident in systems operating in a wide range of operating temperatures and with a high level of external influences.

References
[1] Konikov A, Kulikova E and Stifeeva O 2018 MATEC Web of Conferences 251 03062
[2] Konikov A, Konikov G 2017 IOP Conference Series: Earth and Environmental Science 90 012184
[3] Konikov A I 2019 Industrial and Civil Engineering 6 64-69
[4] Konikov A I 2018 Industrial and Civil Engineering 7 84
[5] Borboni A, Aggogeri F, Faglia R 2013 International Journal of Advanced Robotic Systems, 10, art. no. 149 DOI: 10.5772/55539
[6] Konikov A I 2019 BST Journal 2 28
[7] Ivanov N and Gnevanov M 2018 MATEC Web of Conferences 170 01107
[8] Valpeters M, Kireev I, Ivanov N, 2018 MATEC Web of Conferences 170 01106
[9] Gnevanov M V, Ivanov N A 2018 Industrial and Civil Engineering 4 83
[10] Reid J B and Rhodes D H 2016 Conference on Systems Engineering Research Systems Engineering Advancement Research Initiative, Massachusetts Institute of Technology (Huntsville, Alabama)