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BARCODE READER MANAGEMENT WITH THE ATMEL MICROCONTROLLER (I)

BY

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Abstract. This work describes the necessary hardware interface for the direct and reverse scanning of barcodes using a sensor with a laser diode and a phototransistor, controlled by an application system equipped with an ATMEL family microcontroller. The implemented command program reads the EAN 13 barcode for retail products, determines the data structure from the barcode and sends the decoded digits on a personal computer for further processing and for display.

Key words: barcode; barcode reader; pen barcode reader; European Article Number EAN13; ATMEL microcontroller; command program.

1. Introduction

The hardware structure of the simplest barcode readers basically contains a laser diode, a phototransistor and an optical system, all of them embedded into a pen. The user moves the pen reader by hand, from one end of the barcode to the other, with a fairly constant speed. While moving, the laser diode pen reader generates a light beam over the barcode. From the resulting reflected light, the output of the phototransistor generates a pulse train which is processed by a microcontroller for decoding the data (Fig.1).

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Fig. 1

The barcodes presently used are generally unidimensional (1D) and can be exclusively numerical or alphanumerical. The evolved ones are bidimensional (2D). The most utilized numerical bar codes are: EAN 13 (international code for retail products); UPC-A (universal code for USA and Canada retail products); CODE 11 (for labeling telecommunications equipment); Interleaved 2 of 5 (compact code used in industry, aerial transport and other fields); Post Net (code used in the US postal services for the automated sorting of mail) and others.

The work presents the structure of the EAN 13 barcode and the command program which decodes it with an ATMEL family microcontroller. Further subsequent works will present the hardware structure for other barcode readers, as well as the afferent command program that decodes other types of unidimensional barcodes.

2. The Structure of the EAN 13 Barcode

The EAN 13 barcode is used worldwide for marking commercial retail products. The system was implemented in 1974 by a group of manufacturers and distributors from 12 European countries in order to develop a standardized system of numbering products. This barcode contains 13 numerical characters which indicate the following:

a) the first 2 or 3 digits determine the prefix of the country where the manufacturer is registered. The founding countries of this code, as well as other big countries, use a 2-digit barcode prefix. The prefix assigned to Romania by the International Association for Article Numbers is 594;

b) the next 4 or 5 digits determine the identification number of the manufacturer, according to the 3 or 2-digit prefix country. This number is allocated by a National Coding Center in each country;

c) the next 5 digits determine the identification number of the product. These numbers are distributed according to rules set by the national Coding Center in each country;

d) the last digit is for control. It determines if the digits in the barcode were read and decoded correctly or erroneously.

An example of an EAN 13 barcode is shown in Fig. 2, with the country prefix for Romania – 594, for the manufacturer – 9,876, for the product – 54,321 and the control digit – 9.

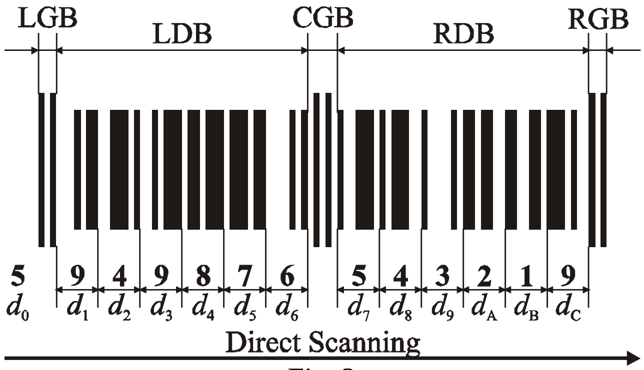

Fig. 2

The EAN 13 barcode represents a succession of dark colored bars (usually black), printed on a light-colored background (usually white). The spaces between the black bars will be from here on referred as "white bars". The alternation of black and white bars, the varying width and the strong contrast allow to easily decode the data.

The direct scan of an EAN 13 barcode, from left to right, consists of reading: the guard bars from the left, which mark the beginning of the barcode; the bars for 6 digits from the left half of the barcode; the central guard bars, that mark the middle of the barcode; - the bars for 6 digits from the right half of the barcode; the guard bars from the right, that mark the ending of the barcode (all the guard bars are slightly higher than the digit bars; the d_0 digit is not physically illustrated with bars in the code structure).

There are 3 left guard bars (LGB) in the EAN 13 barcode, they have alternating colors, they begin with a black colored bar and have the same width (w). This barcode actually starts with a white bar with a width larger than 10w and constitutes the beginning bar of the code, but which, subsequently, is not taken into account because of its unspecified width. A black bar with w width is coded as a logical 1, while a white bar w wide is coded as a logical 0. The 3 left guard bars are coded in binary as 101.

The left half digits bars (LDB) of the EAN 13 barcode are utilized for the $d_1,\ldots,d_6$ digits. Every digit is encoded with 4 alternating colors bars with equal or different widths. The left half digits always have the first bar colored white. Any given bar of a digit can have one of these widths: w, 2w, 3w or 4w, the sum of the bars widths for a digit being always 7w.

The d_1 digit is always encoded as a left A-character. In Table 1 we present the coding of decimal digits as left A-characters.

Table 1

Digits $d_1,...,d_6$	Barcodes	Left A-Character	
		Binary	Hexadecimal
0		0001101	0D
1		0011001	19
2		0010011	13
3		0111101	3D
4		0100011	23
5		0110001	31
6		0101111	2F
7		0111011	3B
8		0110111	37
9		0001011	0B

The $d_2,\ldots,d_6$ digits are coded as left A-characters or as left B-characters. In Table 2 we present the encoding of all decimal digits as left B-characters.

Table 2

Digits $d_2,...,d_6$	Barcodes	Left B-Character	
		Binary	Hexadecimal
0		0100111	27
1		0110011	33
2		0011011	1B
3		0100001	21
4		0011101	1D
5		0111001	39
6		0000101	05
7		0010001	11
8		0001001	09
9		0010111	17

The d_0 digit doesn't have physical bars in the EAN 13 barcode. It is given by the coding alternation of digits $d_1,\ldots,d_6$ as left A or B-characters.

Table 3 presents the encodings for digits $d_1,\ldots,d_6$ as left A or B characters, for all decimal digits from which the digit d_0 is established; a left A-character is encoded as logical 0, while a left B-character is logical 1.

There are five central guard bars (CGB) which have alternating colors, starting with white and having the same width w. They are binary encoded as 01010.

The right half digits bars (RDB) of the EAN 13 barcode are utilized for the $d_7,\ldots,d_C$ digits. Every digit is similarly encoded with 4 alternating colors bars but in this case, the first bar of every digit is black. The other rules described above for the digit bars apply also.

Table 3

Digit d_0	Left A or B-Character		
	d_1 d_2 d_3 d_4 d_5 d_6	Binary	Hexadecimal
0	A A A A A A	000000	00
1	A A B A B B	001011	0B
2	A A B B A B	001101	0D
3	A A B B B A	001110	0E
4	A B A A B B	010011	13
5	A B B A A B	011001	19
6	A B B B A A	011100	1C
7	A B A B A B	010101	15
8	A B A B B A	010110	16
9	A B B A B A	011010	1A

The $d_7,\dots,d_C$ digits are encoded as right C-characters. Table 4 presents the encodings of the decimal digits as right C-characters.

Table 4

Digits $d_7,\dots,d_C$	Barcodes	Right C-Character	
		Binary	Hexadecimal
0		1110010	72
1		1100110	66
2		1101100	6C
3		1000010	42
4		1011100	5C
5		1001110	4E
6		1010000	50
7		1000100	44
8		1001000	48
9		1110100	74

The digit d_C is a control one and has the role to determine if the scanning and decoding of the EAN 13 barcode was made with or without errors. The calculation of this digit is done as follows:

i) the even range digits from the barcode (without the control digit) are summed (S_E) and the odd range digits are summed (S_O) as well:

$$S_E = d_0 + d_2 + d_4 + d_6 + d_8 + d_A$$

$$S_O = d_1 + d_3 + d_5 + d_7 + d_9 + d_B$$

ii) the sum of the even range digits is added to the sum of odd range digits multiplied by 3:

$$S = S_E + 3 \bullet S_O$$

iii) the control digit will be determined as the smallest natural number of one digit, which, added to the previous sum, will produce a result multiple of 10:

$$d_C + S = 10 \bullet n, \ \ d_C = \overline{0 \div 9}, \ \ n \in \mathbb{N}.$$

From the barcode EAN 13 from Fig. 2:

$$S_E = 29, \ S_O = 34, \ S = 131, \ n = 14, \ \ d_C = 9$$

There are 3 right guard bars (RGB) in the EAN 13 barcode, they have alternating colors, they begin with a black colored bar and have the same width (w). This barcode actually ends with a fourth bar that is white and has a width larger than 10w. This is in fact the code ending bar, which, subsequently, is not taken into account because of its unspecified width. The 3 guard bars from the right are coded in binary as 101.

3. The Interfacing and Monitoring of the Pen Barcode Reader

The hardware structure of a barcode pen reader moved manually usually contains a laser diode and phototransistor (Fig. 3). The laser diode (*D*) is powered by the user's closing of the switch (*K*), generating a beam over the barcode. The white bars in the code reflect the light, while the black bars do not.

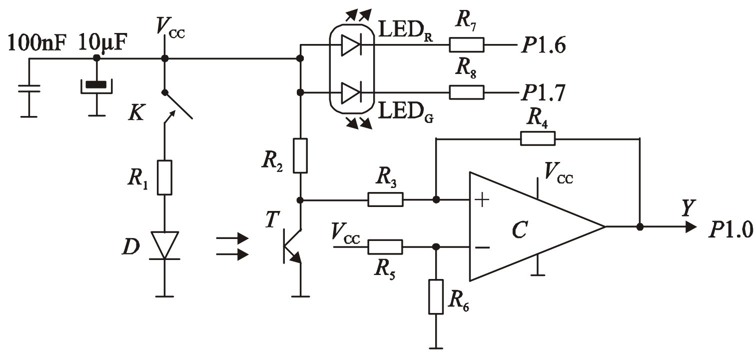

Fig. 3

The phototransistor (*T*), placed in front of the reflected beam, receives the intermittent beam and produces at its collector a pulse train. The phototransistor is connected at the non-inverting input of a hysteresis comparator (*C*) through resistors R_3 and R_4 from the positive feeedback loop, while the inverting input is connected to a threshold voltage obtained by the resistive divisor R_5 and R_6 from V_{cc} (+5V). The positive feedback comparator determines a better resolution and a smaller response time. A bi-color LED will indicate either a barcode reading error when it lights up red (LED_R) or a correct data reading when green (LED_G).

If the laser beam falls on a white bar, it reflects, the phototransistor becomes saturated and the comparator output generates a logical 0. If, on the contrary, the laser beam falls on a black bar, it is not reflected, the phototransistor is blocked and the comparator's output will produce a logical 1. By manually moving the pen reader over the barcode at a fairly constant speed, the white and black bars are converted to logical 0 and respectively 1 levels, while the duration of these levels are proportional with the bars' widths.

Fig. 4 shows the pulse train obtained at the output (*Y*) of the barcode pen reader for a direct scanning of the barcode from Fig. 2. The bars' widths are converted in the durations of the logical levels that, by decoding, produce the binary data and the code standard utilized (A, B or C) that, through further processing, produce the decimal digits of the EAN 13 barcode.

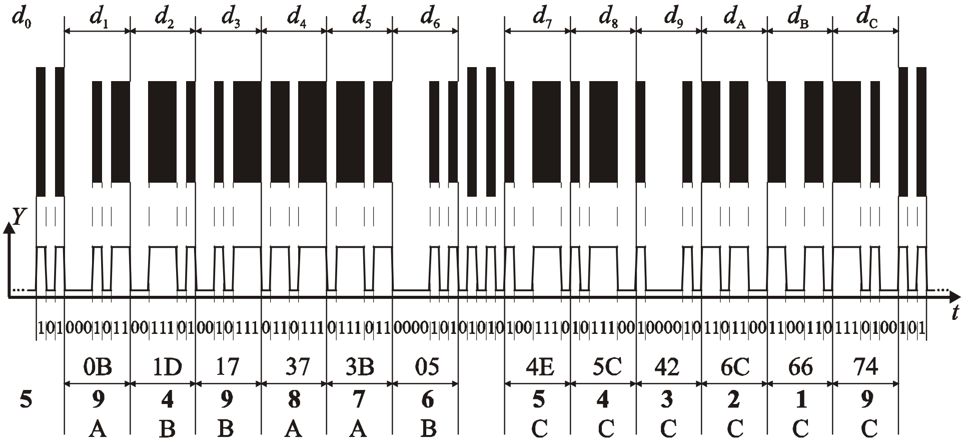

Fig. 4.

The application uses a sensor from the barcode reader MS120A manufactured by Unitech, having the following features: light source 660 nm red LED; scan rate 2 to 75 cm/s; resolution 0.12 mm; scans 1D barcodes; scan range contact; depth of field 0.1 mm; reading angle 0° to 45°; printing contrast scale 0.5 mm; low power consumption. This includes a polished sapphire in order to channel the incident/ reflected laser beams and to reduce the tear of the barcodes labels at scanning.

The command program starts with an initialization sequence for all the required variables, followed by a synchronization sequence during which a black bar is received (if present), then a far larger duration white bar (>10w) that is omitted (the leftmost margin of the barcode) and the first three guard bars from left that must have fairly equal durations. The direct barcode scanning process starts by measuring the guard bars and the digits bars. In order to perform this operation, the pulse train is sampled with a 50 µs period and the logical levels and the corresponding 16-bit time constants are loaded in an internal data memory area.

Table 5 shows the acquired data from the direct scanning of the barcode in Fig. 2, when the pen reader is moved manually. The notes used in the table have the following meanings: N_1 is the logical 1 level; N_0 – logical 0 level; GL – guard levels; GLTC – guard levels time constants; DL – digit levels; DLTC – digit levels time constants; (all the time constants in the table are written in hexadecimal).

Table 5

GL3-GLTC	N_1-5D	N_0-40	N_1-58		
DL_1-$DLTC_1$	N_0-E3	N_1-56	N_0-47	N_1-98	
DL_2-$DLTC_2$	N_0-90	N_1-D9	N_0-42	N_1-51	
DL_3-$DLTC_3$	N_0-8B	N_1-4E	N_0-3D	N_1-C3	
DL_4-$DLTC_4$	N_0-3A	N_1-92	N_0-3F	N_1-BC	
DL_5-$DLTC_5$	N_0-3A	N_1-C0	N_0-34	N_1-7B	
DL_6-$DLTC_6$	N_0-102	N_1-42	N_0-32	N_1-3A	
GL5-GLTC	N_0-35	N_1-39	N_0-35	N_1-3E	N_0-33
DL_7-$DLTC_7$	N_1-3D	N_0-69	N_1-AC	N_0-35	
DL_8-$DLTC_8$	N_1-3C	N_0-37	N_1-A5	N_0-6B	
DL_9-$DLTC_9$	N_1-46	N_0-E1	N_1-47	N_0-2F	
DL_A-$DLTC_A$	N_1-73	N_0-2D	N_1-76	N_0-72	
DL_B-$DLTC_B$	N_1-7C	N_0-6B	N_1-79	N_0-2F	
DL_C-$DLTC_C$	N_1-AC	N_0-32	N_1-43	N_0-64	
GL3-GLTC	N_1-45	N_0-33	N_1-44		

After measuring the right guard bars of the EAN13 barcode, the last white bar, having a much longer duration (> 10w) is received and discarded (the rightmost edge of the code).

Then a program sequence follows, consisting of testing the number of levels received for EAN13, the correct alternation of the guard and digits levels and checking if the acquired time constants are between the admitted lower and upper limit. If all these criteria are met, then the barcode decoding continues. If an error is detected, the barcode processing is abandoned, the LED_R is lit up for 0.5s and the scanning process is resumed.

The processing of the left, center and right guard levels is briefly described below.

1º The time constants' sums (S_{TC}) of the respective guard levels are computed;

2º The average time constants (TC_A) for the guard levels are determined (the sums previously computed are divided by 3 for the left and right guard levels, or by 5 for the central guard levels);

3º The threshold (TS) constants are computed as

$$TS_1 = 0.5 \bullet TC_A$$

and

$$TS_2 = 1.5 \bullet TC_A$$

for a 50% variation of the time constants compared to the average.

4º Each time constant of the guard levels is checked to be within the two threshold constants (TS_1; TS_2). If they are within this interval, then the decoding of the EAN13 barcode continues, otherwise the error is signaled.

The data acquired for the guard levels and for the digits levels respectively are processed and the data obtained are shown in Table 6.

Table 6

	S_{TC}	**TC_A**	**TS_1**	**TS_2**	**TS_3**	**TS_4**	**TS_5**	**Dec**	**Cod**	**Digit**
GL3	F5	51	28	79						
DL_1	218	4C	26	72	BE	10A	156	0B	A	**9**
DL_2	1FC	48	24	6C	B4	FC	144	1D	B	**4**
DL_3	1D9	43	21	64	A7	EA	12D	17	B	**9**
DL_4	1C7	41	20	61	A2	E3	124	37	A	**8**
DL_5	1A9	3C	1E	5A	96	D2	10E	3B	A	**7**
DL_6	1B0	3D	1E	5B	98	D5	112	05	B	**6**
GL5	114	37	1B	52						
DL_7	187	37	1B	52	89	C0	F7	4E	C	**5**
DL_8	183	37	1B	52	89	C0	F7	5C	C	**4**
DL_9	19D	3B	1D	58	93	CE	109	42	C	**3**
DL_A	188	38	1C	54	8C	C4	FC	6C	C	**2**
DL_B	18F	39	1C	55	8E	C7	100	66	C	**1**
DL_C	185	37	1B	52	89	C0	F7	74	C	**9**
GL3	BC	3E	1F	5D						

The processing of the barcode digits levels is briefly described below.

5º The time constants' sums (S_{TC}) of each digit levels are computed.

6º The average time constants (TC_A) for each digit levels are determined for a width w (the sums previously computed are divided by 7).

7º The threshold (TS) constants are computed as

$$TS_1 = 0.5 \bullet TC_A$$

$$TS_2 = 1.5 \bullet TC_A$$

$$TS_3 = 2.5 \bullet TC_A$$

$$TS_4 = 3.5 \bullet TC_A$$

$$TS_5 = 4.5 \bullet TC_A$$

for a 50% variation of the time constants compared to the average.

8º The current level is checked to determine if its time constant falls into one of the intervals (TS_1; TS_2), (TS_2; TS_3), (TS_3; TS_4) or (TS_4; TS_5) which would mean that the corresponding bar has the width w, 2w, 3w or 4w respectively. In this manner, a white bar is binary decoded as 0, 00, 000 or 0000, while a black one is decoded 1, 11, 111 or 1111. If the current level does not have the time constant in one the above intervals, an error is signaled.

9º The four bars of each digit are decoded (Dec) in this manner and a test is performed if the combined width of these four bars is 7w (the number of the binary decoded values of each digit must be 7).

10º A linear transformation is used to determine the utilized code (Cod) and the corresponding decoded decimal digit ($d_1,\ldots,d_C$).

11º For a direct scanning a test is performed to determine if the first digit (d_1) is encoded with a left A-character, the following 5 digits ($d_2,\ldots,d_6$) are encoded with left A or B-characters and the last 6 digits ($d_7,\ldots,d_C$) are encoded with right C-characters. An error is signaled if one of the digits does not comply.

12º Digit d_0 is calculated based on the A or B encoding of the digits in the left half of the barcode;

13º The control digit is calculated. If this coincides with the last read digit of the barcode, then the data is correctly decoded and LED_G is lit for 1 second; otherwise, the error is signaled and the barcode reading is resumed.

4. Conclusions

The hardware structure described was built in practice, it is very simple and consists of a laser diode and a phototransistor along with a few external components. They are managed by an application system equipped with microcontroller AT89S8253. For testing purposes, the MS120A pen reader was used, but also the H0A6480 sensor manufactured by Honeywell. These transducers have a good resolution and allow the reading of barcodes with a width larger than 0.25 mm.

The command program implements a few barcode EAN13 scanning functions, that acquires the time constants, computes the sum of the time constants, the time constants averages, the threshold constants, checks if the logical levels fall into certain intervals, decodes the bars for each digit, determines the numeric values of the decimal digits, compute the first digit of the barcode and the control digit which it checks etc.

The command software for this application is written in machine code, requires a program memory space of 3.2 KB and stands out by its small memory volume compared to its features. A program sequence is developed for the reverse barcode scanning. This is based on a testing program that detects automatically the direction of scanning.

In a similar way, command programs may be developed for software decoding of any type of unidimensional numeric or alphanumeric barcode.

It must be pointed out that the manual swipe of the pen reader by the user is a drawback because the durations of the logical levels may vary quite significantly, which may result in scanning errors and in the need to repeat the scanning procedure.

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MANAGEMENTUL CITITORULUI DE CODURI DE BARE CU MICROCONTROLER ATMEL (I)

(Rezumat)

Lucrarea descrie interfața hardware necesară pentru scanarea directă şi inversă a codurilor de bare utilizând un senzor cu diodă laser şi un fototranzistor controlate de un sistem de aplicație echipat cu microcontroler din familia ATMEL. Programul de comandă implementat citeşte codul de bare EAN 13 pentru produsele de retail, determină structura de date conținută de codul de bare şi transmite la un calculator personal cifrele decodificate pentru alte prelucrări şi afişare.