Development of automated control system for waste sorting

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Abstract. A crucial prerequisite for recycling forming an integral part of municipal solid waste (MSW) management is sorting of useful materials from source-separated MSW. The morphological composition of the waste generated in Russia was studied. Theoretical bases of management of the waste sorting conveyor have been developed taking into account failures such as uneven loading and uneven sorting of waste. The calculation of the waste material balance was based on solving the system of Euler equations and flow control. Control laws are defined to control the flow and density of waste on the conveyor. A relay-contact scheme for automatic sorting of waste to extract various fractions of recyclable waste, such as metal, plastic, paper, glass and organic matter from MSW was developed. The synthesis of a finite state of a machine control system for waste sorting is implemented on a programmable logic device Omron.

1. Introduction
In 2018, Russia produced 63 million tons of municipal solid waste (MSW) and was estimated to increase 2-4\% per year. Approximately 30\% of the waste was consisted of paper, 35\% was consisted of food waste, 3\% – glass, 6\% – recycled plastic and metal. In 2019, amendments to articles 5 and 12 of the Federal Law “On Production and Consumption Wastes” come into effect. Much attention is paid to the construction of modern sorting and processing facilities. By 2024, 200 waste disposal plants should appear in Russia. Now there are 117 waste recycling plants in the country, but of these, only 38 can be called modern, and therefore the development of algorithms and waste sorting methods is an urgent task.

2. Equipment and devices used in the studies
The theoretical part of the article was developed using the General systems theory and the theory of Finite-state machine. In practical implementation the authors use the microcontroller OMRON. We study monitoring and control of waste sorting with the OMRON CX-Programmer and CX-Designer software.
3. The results of the study and their discussion

3.1. Sorting station waste stream description
Let’s describe the material environment as orderly moving waste fractions. We shall consider movement of waste along the conveyor. On a piece \([x, x+\Delta x]\), will be is \(\Delta n\) waste in time \(\Delta t\) (figure 1) [1].

\[
\frac{\partial q}{\partial t} = -\frac{\partial \rho(x,y,t)}{\partial x} - \frac{\partial \rho(x,y,t)}{\partial y} + b(x,y,t)
\]

(1)

\[
q(x,y,t) = u(x,y,t) + z(x,y,t)
\]

(2)

\[
u = k_1 \rho + k_2 q
\]

(3)

\[
\iint \rho(x,y,t) \, dx \, dy \rightarrow \min
\]

\[
x_0 \leq x \leq x_1, y_0 \leq y \leq y_1, t \geq t_0, q(x_0,y_0,t) = q_0(t),
q(x_1,y_1,t) = q_1(t), \rho(x,y,t_0) = \rho_0(x,y),
\rho_s = vq_s, \rho_y = wq_s.
\]

(4)

Substituting (3) in (1):

\[
q(x,y,t) = k_1 \rho + k_2 q + z; \quad \rho = \frac{k_2 q + z}{1 - k_1}
\]

(5)

Substituting (5) in (1):

\[
\frac{\partial q}{\partial t} + k_1 \frac{\partial \rho}{\partial x} + k_2 \frac{\partial q}{\partial x} + k_1 \frac{\partial \rho}{\partial y} + k_2 \frac{\partial q}{\partial y} = -b(x,y,t)
\]

Considering (4) will get

\[
\frac{\partial q}{\partial t} + k_1 \frac{\partial q}{\partial x} (k_1 v + k_2) + \frac{\partial q}{\partial y} (k_1 \omega + k_2) = -b(x,y,t).
\]
Let’s make the equation of characteristics

\[
\frac{dr}{dt} = \frac{dx}{k_1 v + k_2} = \frac{dy}{k_1 v + k_2} = \frac{-dq}{b}.
\]

\[
\begin{align*}
q_1 &= q + \int bdr \\
q_2 &= (k_1 v + k_2) t - x \\
q_3 &= (k_1 v + k_2) t - y
\end{align*}
\]

At \(x = 0\)

\[
q_1 = -e^{\frac{-k_2 t}{v}} \\
q_2 = (k_1 v + k_2) t - x \\
q_3 = (k_1 v + k_2) t - y
\]

\[
q = -\int bdr - e^{\frac{(k_2 t + k_2) t - x}{2k_2(t + v)}}
\]

in this way

\[
\rho = \frac{k_1 q + z}{1 - k_1}
\]

Control actions for the flow and density of waste on the conveyor were obtained.

3.3. Automated sorting techniques for various MSW fractions

Relay contact circuit was developed to automatically sort waste to extract various fractions of recyclable waste, such as metal, plastic, paper, glass, and organic matter from MSW. An overview on automated sorting of source-separated municipal solid waste was discussed in the article [2–4]. Waste sorting technologies are shown in table 1.

### Table 1. Sorting techniques based upon composition of MSW.

| MSW fractions | Sorting technique |
|---------------|------------------|
|               | Screw-Press (x1) | Shredder (x2) | Magnetic (x3) | Pneumatic (x4) | Optical (x5) | Spectral (x6) |
| Organic (y1)  | +                | +              |               |               |               |               |
| Metal (y2)    |                  |                | +              |               |               |               |
| Plastic (y3)  |                  |                | +              |               |               |               |
| Paper (y4)    |                  |                | +              |               |               |               |
| Glass (y5)    |                  |                | +              |               |               |               |
| Unsorted (y6) | +                | +              | +              | +              | +              | +              |

Figure 2 illustrates the entire process flow of automated sorting of recyclable materials from MSW.

![Figure 2](image-url)
To design a ladder circuit, you must specify the input and output streams and equipment addresses (table 2).

**Table 2.** Addresses of contacts and coils of the ladder diagram.

| In (Sorting technique) | Out (MSW fractions) |
|------------------------|---------------------|
| Name | Address | Comment | Name | Address | Comment |
| x1  | 0.00 | Screw-Press | y1 | 100.00 | Organic |
| x2  | 0.01 | Shredder | y2 | 100.01 | Metal |
| x3  | 0.02 | Magnetic | y3 | 100.02 | Plastic |
| x4  | 0.03 | Pneumatic | y4 | 100.03 | Paper |
| x5  | 0.04 | Optical | y5 | 100.04 | Glass |
| x6  | 0.05 | Spectral | y6 | 100.05 | Unsorted |

Built truth table of waste sorting equipment (table 3).

**Table 3.** Truth table.

| x1 x2 x3 | x1 x2 x3 | x1 x2 x3 | x1 x2 x3 | x1 x2 x3 | x1 x2 x3 | x1 x2 x3 | x1 x2 x3 |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 0 0 0 0 0 0 0 0 | 0 0 0 0 0 0 0 0 | 0 0 0 0 0 0 0 0 | 0 0 0 0 0 0 0 0 |
| 0 0 1 0 1 0 0 0 | 0 0 1 0 1 0 0 0 | 0 0 1 0 1 0 0 0 | 0 0 1 0 1 0 0 0 |
| 0 1 0 0 0 0 0 0 | 0 1 0 0 0 0 0 0 | 0 1 0 0 0 0 0 0 | 0 1 0 0 0 0 0 0 |
| 0 1 1 0 0 0 0 0 | 0 1 1 0 0 0 0 0 | 0 1 1 0 0 0 0 0 | 0 1 1 0 0 0 0 0 |
| 1 0 0 0 0 0 0 0 | 1 0 0 0 0 0 0 0 | 1 0 0 0 0 0 0 0 | 1 0 0 0 0 0 0 0 |
| 1 0 1 0 1 0 0 0 | 1 0 1 0 1 0 0 0 | 1 0 1 0 1 0 0 0 | 1 0 1 0 1 0 0 0 |
| 1 1 0 1 0 0 0 0 | 1 1 0 1 0 0 0 0 | 1 1 0 1 0 0 0 0 | 1 1 0 1 0 0 0 0 |
| 1 1 1 0 0 1 1 0 | 1 1 1 0 0 1 1 0 | 1 1 1 0 0 1 1 0 | 1 1 1 0 0 1 1 0 |

3.4. Synthesis of combinational logic circuits

To obtain logical equations of the equipment operation we have received a minimal disjunctive normal form using Karnaugh map (table 4–9) [5].

**Table 4.** Karnaugh map (Organic).

| x2 x3 | x2 x3 | x2 x3 |
|-------|-------|-------|
| x1    | 00    | 00    |
|       | 01    | 01    |
|       | 11    | 11    |
|       | 10    | 10    |

\[ y_1 = x_1 \overset{2}{x_2} x_3 \]

**Table 5.** Karnaugh map (Metal).

| x2 x3 | x2 x3 | x2 x3 |
|-------|-------|-------|
| x1    | 00    | 00    |
|       | 01    | 01    |
|       | 11    | 11    |
|       | 10    | 10    |

\[ y_2 = x_1 x_2 x_3 \]

**Table 6.** Karnaugh map (Plastic).

| x5 x6 | x5 x6 | x5 x6 |
|-------|-------|-------|
| x4    | 00    | 00    |
|       | 01    | 01    |
|       | 11    | 11    |
|       | 10    | 10    |

\[ y_3 = x_4 x_5 x_6 \]

**Table 7.** Karnaugh map (Paper).

| x5 x6 | x5 x6 | x5 x6 |
|-------|-------|-------|
| x4    | 00    | 00    |
|       | 01    | 01    |
|       | 11    | 11    |
|       | 10    | 10    |

\[ y_4 = x_4 x_5 x_6 \]
Table 8. Karnaugh map (Glass).

| x4 | 00 | 01 | 11 | 10 |
|----|----|----|----|----|
| x5 | 0  | 0  | 0  | 0  |
| x6 | 1  | 1  | 0  | 1  |

\[ y_5 = x_4 x_5 x_6 \]

Table 9. Karnaugh map (Unsorted).

| x4 | 00 | 01 | 11 | 10 |
|----|----|----|----|----|
| x5 | 0  | 0  | 0  | 0  |
| x6 | 0  | 0  | 0  | 0  |

\[ y_6 = x_4 x_5 x_6 \]

On the basis of the obtained logical equations Ladder Diagram has been developed using the Omron software and hardware complex (figure 3) [6].

Figure 3. A fragment Ladder Diagram.

Conclusions
The paper solved the problem of managing the material flow of the waste recycling conveyor with allowance for disturbances, such as failure and unevenness of the density of the waste stream. A ladder diagram of the operation of equipment for sorting waste into fractions using Omron software and hardware was developed.

References
[1] Sereda T G and Kostarev S N 2018 IOP Conf. Ser.: Materials Science and Engineering 450 062009
[2] Gundupalli S P, Hait S, Thakur A 2017 A review on automated sorting of source-separated municipal solid waste for recycling Waste Management 60 56–74
[3] Tang J, Wei L 2018 Source analysis of municipal solid waste in a mega-city (Guangzhou): Challenges or opportunities? Waste Management and Research 36 (12) 1166–76
[4] Ionescu G, Rada E C, Cioca L I 2015 Municipal solid waste sorting and treatment schemes for the maximization of material and energy recovery in a latest EU member Environmental Engineering and Management Journal 14 (11) 2537–44
[5] Karnaugh M 1953 The Map Method for Synthesis of Combinational Logic Circuits Transactions of the American Institute of Electrical Engineers 172 (9) 593–9
[6] Kostarev S N and Sereda T G 2017 Development of software and hardware models of monitoring, control, and data transfer to improve safety of downhole motor during drilling IOP Conference Series: Earth and Environmental Science 87(3) 032016