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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 Δn waste in time Δt (figure 1) [1].

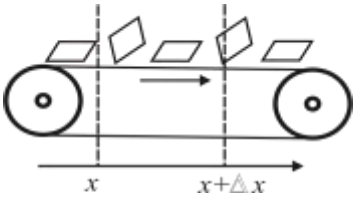

Figure 1. Movement of waste along the conveyor.

Discrete system we shall replace with continuous model. The law of movement of details will be determined by function $n=n(x, t)$ from two variables x, t. We shall consider this dependence at x=const, t = const and x, t = const. At x=const we pass to concept of a stream:

$$q = \lim_{\Delta t \to 0} \frac{\Delta n_t}{\Delta t}\bigg|_x = \frac{dn}{dt}\bigg|_x .$$

At t = const we pass to concept of density, what quantity of waste is on piece Δx at the moment of time t:

$$\rho = \lim_{\Delta t \to 0} \frac{\Delta n_x}{\Delta x_t}\bigg|_t = \frac{dn}{dx}\bigg|_t$$

3.2. Statement of management problem by processing waste on conveyor

Infringement of uniformity of distribution of waste on a technological route there can be two types: a defect and halting. Updating of a waste material stream consists of change of speed v or intensity of a stream q. Movement of details we shall consider in two-dimensional Cartesian system of coordinates. We shall allocate an interval with the ends on which there is a portion of a waste. Axis x is used for the description of a condition of a waste stream from a defect, an axis y – for the description of a condition of a stream from the failure connected to work of the equipment (1).

$$\begin{cases} \dfrac{\partial q}{\partial t} = -\dfrac{\partial \rho(x,y,t)}{\partial x} - \dfrac{\partial \rho(x,y,t)}{\partial y} + b(x,y,t) & (1) \\ q(x,y,t) = u(x,y,t) + z(x,y,t) & (2) \\ u = k_1\rho + k_2 q & (3) \\ \iiint \tilde{\rho}(x,y,t)\,\mathrm{d}x\mathrm{d}y\mathrm{d}t \to \min \end{cases}$$

$$x_0 \le x \le x_k,\ y_0 \le y \le y_k,\ t \ge t_0,\ q(x_0, y_0, t) = q_0(t),$$
$$q(x_k, y_k, t) = q_k(t), \rho(x, y, t_0) = \rho_0(x, y),$$
$$\rho_x = vq_x, \rho_y = wq_y. \quad (4)$$

Substituting (3) in (1):

$$q(x,y,t) = k_1\rho + k_2 q + z; \quad \rho = \frac{k_2 q + z}{1 - k_1} \quad (5)$$

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

$$dt = \frac{dx}{k_1 \nu + k_2} = \frac{dy}{k_1 \omega} = -\frac{dq}{b}.$$

$$\begin{cases} q_1 = q + \int b dt \\ q_2 = (k_1 \nu + k_2)t - x \\ q_3 = (k_1 \omega + k_2)t - y \end{cases} \quad At\ x = 0 \quad \begin{cases} q_1 = -e^{-t} \\ q_2 = (k_1 \nu + k_2)t - x \\ q_3 = (k_1 \omega + k_2)t - y \end{cases} \quad or\ \ q_1 + e^{\frac{c_2 + c_3}{2k_2 + k_1(\nu + \omega)}} = 0 \tag{6}$$

in this way

$$\begin{cases} q = -\int b dt - e^{\frac{(k_1 \nu + k_2)t - x + (k_1 \omega + k_2)t - y}{2k_2 + k_1(\nu + \omega)}} \\ \rho = \dfrac{k_2 q + z}{1 - k_1} \end{cases}.$$

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.

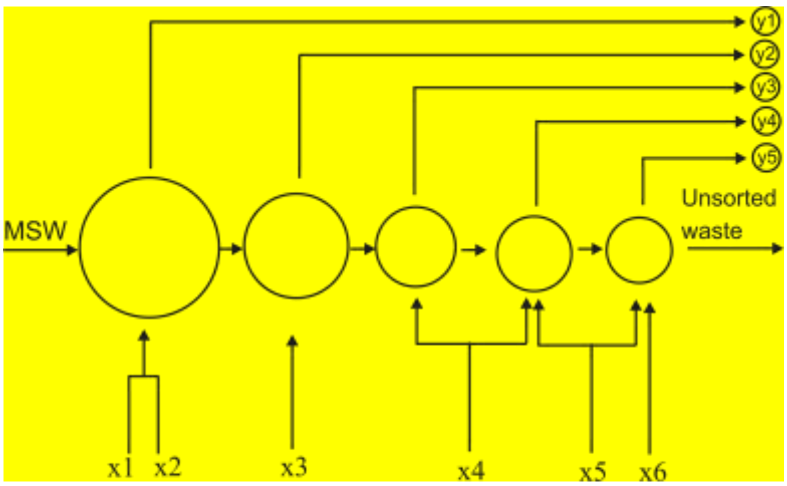

Figure 2. Flow diagram of automated sorting of recyclables from MSW.

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.

Separation methods			MSW fractions		Separation methods			MSW fractions			
x1	x2	x3	y1	y2	x4	x5	x6	y3	y4	y5	y6
0	0	0	0	0	0	0	0	0	0	0	1
0	0	1	0	1	0	0	1	0	0	0	0
0	1	0	0	0	0	1	0	0	0	0	0
0	1	1	0	0	0	1	1	0	0	1	0
1	0	0	0	0	1	0	0	0	0	0	0
1	0	1	0	0	1	0	1	1	0	0	0
1	1	0	1	0	1	1	0	0	1	0	0
1	1	1	0	0	1	1	1	0	0	0	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).

x1 \ x2x3	00	01	11	10
0	0	0	0	0
1	1	0	0	0

$y_1 = x1x2\overline{x3}$

Table 5. Karnaugh map (Metal).

x1 \ x2x3	00	01	11	10
0	0	0	1	1
1	0	0	0	1

$y_2 = \overline{x1}\,\overline{x2}x3$

Table 6. Karnaugh map (Plastic).

x4 \ x5x6	00	01	11	10
0	0	0	0	0
1	1	1	0	1

$y_3 = x4\overline{x5}x6$

Table 7. Karnaugh map (Paper).

x4 \ x5x6	00	01	11	10
0	0	0	0	0
1	0	0	0	1

$y_4 = x4x5\overline{x6}$

Table 8. Karnaugh map (Glass).

x4 \ x5x6	00	01	11	10
0	0	0	0	0
1	1	1	0	1

$y_5 = \overline{x4}x5x6$

Table 9. Karnaugh map (Unsorted).

x4 \ x5x6	00	01	11	10
0	0	0	0	0
1	0	0	0	1

$y_6 = \overline{x4}\,\overline{x5}\,\overline{x6}$

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

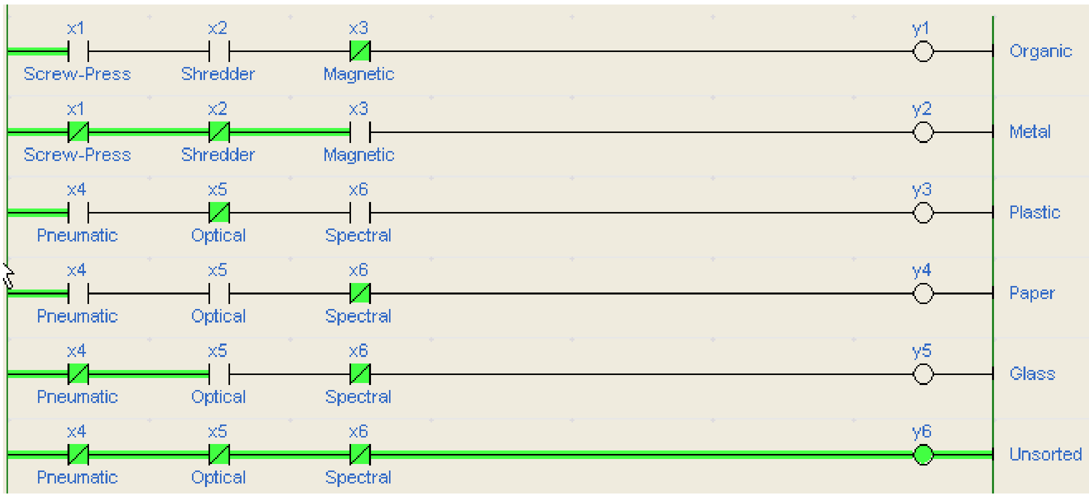

Figure 3. A fragment Ladder Diagram.

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.

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