Krzysztof STANKIEWICZ
Institute of Mining Technology KOMAG, Gliwice
kstankiewicz@komag.eu

SELF-ORGANIZATION OF NETWORK STRUCTURE BASED ON SWARM ALGORITHMS

Key words

Automation, artificial intelligence methods, swarm algorithms.

Abstract

A concept of the method enabling the self-organization of complex monitoring structures and data transmission into single virtual traffic routes, which are reliable communication media, is presented. Systems based on similar techniques have a high tolerance to interferences and enable dynamic and spontaneous changes in hardware and software to adapt quickly to changing conditions. In industry, there are complex communication systems for the transmission of visual, voice and digital data from the monitoring or control systems. The described method of the self-organization of a multi-agent system is primarily prepared for the implementation of an innovative system for monitoring of rollers of belt conveyors.

Introduction

From 1950, leading university centres study, investigate and develop the methods and technologies of artificial intelligence. Many of the developed technologies have been implemented in engineering practice, especially for optimization of processes, the recognition of standards, teaching the machines, modelling, prediction, adaptation, etc. [6, 7, 11, 12, 16]. Artificial intelligence enables efficient control and automation of the processes, which so far could be done only by a man. Solutions using the artificial intelligence enable partial or even total elimination of people from the highly hazardous areas as well as early detection of hazards and sending warning signals.

In the mining industry, artificial intelligence is used especially in diagnostics of the wear of subassembly and components [13] and the wear of machines of control systems and mechanization systems [4, 5]. Implementations, which enable intelligent adaptation of machines to changeable operational conditions, are known. Future extraction of coal seams of high methane content, mining in thin seams as well as bumping and thermal hazards force designers to develop a system of higher and higher autonomy, so the role of man would be limited only to remote control and supervision.

1. Fire hazards in transportation with use of belt conveyors

Fire is one of the most frequent hazards in the mining industry, especially in hard coal mines, which often requires long-time rescue actions. Fire-fighting actions, in the case of active extinguishing, result in the suspension of mining operations in the affected part of the coalmine, and in the case of passive extinguishing, it is necessary to dam the workings to isolate them, which result in more fixed assets and coal in the area of fire [9].

Open fire in underground working means the presence of glowing or burning substances, as well as the persistence of smoke in mine air or the persistence of carbon monoxide of concentration higher than 0.0026% in the air stream [9].

In the area of such hazard, there is a mine transportation system, i.e. internally organized group of objects on the surface and underground as well as relationships between these objects and their properties, oriented onto meeting the assumed transportation objectives [2, 11]. The system is responsible for the following transportation tasks: transportation of the run-of-mine ore, the transportation of people and materials, as well as the reloading and storing of the transported materials [1, 2, 14, 15].

Due to the scale of technological processes, it can be said that a mining plant is mainly a transportation enterprise. In this area, there is a series of hazards associated mainly with maintenance, operational conditions, and emergency states. The hazard of fire, which can occur in belt conveyors that transport run-of-mine ore, is one of the significant hazards. Friction of conveyor belt on the following can be a source of belt conveyors fires:

- Support or run-of-mine ore that falls from the conveyor,
- Drums during slippage caused by overloading the conveyor, and
- Blocked rollers.

Quite often, there is a problem with failure of rollers due to seized bearing systems. Rotary speed of the roller not correlated with a linear speed of the transportation belt becomes the source of fire hazard due to thermal effects caused by friction. A hot roller may not ignite the run-of-mine ore or belt during its movement, but after conveyor belt stoppage, the fire is inevitable.

2. Monitoring of belt conveyor rollers in the aspect of fire protection

Some examples of developed systems for monitoring of condition of rollers can be found in the literature [10, 12]. The movement of belt, its break, as well as its speed are controlled. Regarding fire protection, these systems are mainly based on a direct measurement of temperature near the bearing rollers' enclosures with use of the sensors, installed on the conveyor, thermovision systems, or pyrometers. The use of a fixed thermovision system is economically unjustified and technically difficult due to the presence of dust in the atmosphere. That is why periodical inspections with use of movable devices are carried out for the control purpose. Such control requires an employee to record and analyse the observed temperatures. It is inconvenient and ineffective.

There are also more complex systems, which not only analyse the temperature near the bearing enclosures, but also chemical composition of surrounding atmosphere. Their main task is to detect the source of fire. The solution of the detection of emergency states and sources of belt conveyor fires, developed by the Institute of Innovative Technologies EMAG, can be an example [10]. This system has a multi-detector measuring system installed along the entire conveyor. The temperature of conveyor design, the concentration of carbon monoxide, the concentration of hydrogen cyanide, and smoke are measured.

The system performs the following:

- Measures physical amounts,
- Eliminates signals from damaged sensors,
- Filters analogue signals,
- Unifies signals to the common risk factor,
- Calculates the common risk factor,
- Classifies signals and factors and determines emergency states, and
- Visualizes or transmits the emergency state to the central unit.

The solution for diagnostics of belt conveyors, suggested by the Wroclaw University of Technology, is based on the analysis of the following known factors [17]:

- Vibrations generated by rotating sub-assemblies during normal operation of conveyor,
- The temperature of the bearings' enclosures, and
- The current used by drive motors.

This system does not directly react to fire hazards, but it enables early elimination of emergency states of the conveyor, preventing the factors causing fire.

The system developed by the Delft Technical University (The Netherlands) appeared on the market recently. Each roller is equipped with a small and economical electronic system, the *Monitoring and Transmission Unit* (MTU), which enables measuring the temperature and rotary speed, as well as short-range wireless transmission. The cell is a source of power supply. Each MTU installed in a roller is the component of a global (in the scale of conveyor) communication link. Communication goes from one roller to another, while each unique own number, the number of the neighbouring MTU to which measuring data is to be transmitted, and the number of the MTU from which the data can be received are recorded in the memory of each MTU. This transmission topology is not flexible enough for the range of reaction to MTU emergency states, because the system has a externally defined communication network, which cannot adapt itself to potential problems, making exchange of data between MTU series, assumed at the start-up stage, impossible. The main, external sending-receiving stations can be located at driving drums, end drums, or at any roller. Wireless communication with the conveyor monitoring system, the possibility of making analyses, and archiving the received data are the main functions of the station. The station can communicate with any roller, at which itis located, creating at a given point for the link for the aggregation of data from the entire system. There are the following main disadvantages of the suggested solution:

- The cell power supply of MTU, which requires periodical replacement;
- The lack of intrinsically safe manufacture; and,
- The lack of a self-organizing logic link of data in a complex system of hundreds MTU units, which is especially problematic in the emergencies.

3. Concept of the method for the self-organization of the communication swarm of rollers

Elimination of all above-mentioned disadvantages of the monitoring system of belt conveyor rollers by the Technical University in Delft inspired the KOMAG Institute of Mining Technology to develop the following solutions:

- A system for the recuperation of energy from the rotating roller, which enables the MTU to get full self-sufficiency and automation regarding power supply (according to the idea of *energy harvesting*, which bases on several technical solutions of energy recovery from movement, vibrations, electromagnetic fields or heat sources that can be found in almost each technological process);

- An intrinsically safe hardware platform, which enables measuring the temperature of the roller in specified points, measuring its rotational speed, and the wireless receiving and transmission of data at a distance less than 2 m;
- A self-organizing structure of rollers communication system reacting to and including the following:
  - Conveyor start up, when all MTU are supplied by the energy harvesting system, are gradually activated;
  - The emergency state of MTU hindering communication and transmission of data.

The concept of a self-organizing structure is based on one of the artificial intelligence technologies known as the "intelligence of swarm" [3], which is a direct implementation of the phenomena and behaviour observed in nature among organisms living in groups. In 1987, during the SIGGRAPH conference, the programmer Craig Reynolds, in the paper entitled "*Flocks, Herds, and Schools: A Distributed Behavioural Model,*" suggested three basic rules of self-organization based on observed groups of animals [8] as follows:

- Collision avoidance – control eliminating local concentration of individuals,
- Flock centering – actions towards the average behaviour of the local group of individuals, and
- Velocity matching – actions towards the average objective of local group of individuals.

Coefficient of transmission priority W_p, which determines the efficiency of data transmission to the main sending-receiving stations, is assigned to each data frame passing through MTU in the communication system. This coefficient is based on the time of data propagation and the number of jumps of transmitted frames with the measuring data. Moreover, the following communication functions should be assigned to each data frame, and these limitations will form rules governing the mathematical algorithm of the system:

1. Matching the transmission path with data frames from neighbouring MTUs;
2. Trying to occupy the place in the path between data frames from MTU that are in the transmission range;
3. Prohibiting the competition for primacy in transmission with frames of higher priority;
4. Avoiding transmission by the units marked as damaged; and,
5. Disengaging present connection, when the coefficient of transmission priority of MTU group falls or the main transceiver station was found.

These functional limitations on the MTU group, which makes the transmission connection, creates the structure of a reliable transmission path by itself, neglecting the damaged units – just like living creatures are able to separate into two independent groups when meeting an obstacle, then reuniting into a single group again. The frame of data can be defined by the following four additional values:

- Its own, which is the unique identification number for each MTU;
- X and Y coordinates defining the position they occupy in the structure of the communication path;
- The priority coefficient W_p of the communication path, where the given frame is its element; and,
- The speed of transmission for dimension *X* and *Y*, i.e. *vX* and *vY.*

Other frames that are within the range of MTU transmission, i.e. ones which are at a sufficiently small distance *d* and at the same time are in the field of vision determined by virtual angle *r*, are the neighbours of the fames having the number of a given MTU.

To check if the given frame *e* of coordinates *e.X* and *e.Y,* respectively, is the neighbour of MTU *b* of coordinates *b.X* and *b.Y*, we must first check if the element is in a sufficiently small distance away, that is

$$\sqrt{(e.X - b.X)^2 + (e.Y - b.Y)} < d \tag{4.1}$$

where:

e.X, e.Y – coordinates of frame *e,*
b.X, b.Y – coordinates of frame MTU *b,*
d – distance to the neighbour frame.

If inequality is not satisfied, then the following rules are not to be verified as the given frame from MTU *e* is surely not a neighbour of frames from MTU *b*. If inequality is satisfied, we should check if the frame is within the virtual angle of field of vision *r* by the determination of angle r_1, under which the frame moves virtually:

$$r_1 = \arctan\left(\frac{b.vY}{b.vX}\right) \tag{4.2}$$

where:

r_1 – virtual angle of movement of frame,
b.vY, b.vX – speed of frame transmission for dimension *X* and *Y.*

As well as virtual angle r_2 of the section connecting the frame MTU *b* with the frame MTU *e*:

$$r_2 = \arctan\left(\frac{e.Y - b.Y}{e.X - b.X}\right) \tag{4.3}$$

where:

r_2 – virtual angle of section connecting the frame MTU *b* with the frame MTU *e.*

Assuming that $b.vX \neq 0$ and $e.X\text{-}b.X \neq 0$. Then the absolute value of the angle difference is calculated and the following inequality is verified:

$$|r_1 - r_2| < r \tag{4.4}$$

where: r – virtual angle of field of vision of frame.

If this inequality is satisfied, the frames are from the neighbouring MTU. Subsequently, the first rule is applied - each frame adjusts its path to the frames from neighbouring MTUs. We should calculate the average speed v_{avg} of all frames from neighbouring MTUs (separately for vX component and vY component), and then we should modify the speed of frame transmission, considering the priority coefficient of the path, current, speed and calculated average value according to the following formula:

$$\begin{aligned} b.vX &= b.vX + \left(W_p \cdot \left(vX_{avg} - b.vX\right)\right) \\ b.vY &= b.vY + \left(W_p \cdot \left(vY_{avg} - b.vY\right)\right) \end{aligned} \tag{4.5}$$

where:

W_p – priority coefficient of the communication path,

vX_{avg}, vY_{avg} – average speed of all frames from neighbouring MTUs.

To use the second rule, we should calculate the average number of frame moves in the transmission path d_{avg}, in relation to the neighbouring MTUs and then modify transmission speed of the frame in relation to the neighbouring frames. Formula (4.6) is the result of using the theorem of triangle similarity. It uses the position of the frame in the transmission path, the speed of which b is modified as well as the neighbour's position e:

$$\begin{aligned} d &= \sqrt{(e.X - b.X)^2 + (e.Y - b.Y)} \\ b.vX &= b.vX + \frac{(e.X - b.X) \cdot \left(d - d_{avg}\right)}{d} \\ b.vY &= b.vY + \frac{(e.Y - b.Y) \cdot \left(d - d_{avg}\right)}{d} \end{aligned} \tag{4.6}$$

where:

d_{avg} – average number of frame moves in the transmission path, in relation to the neighbouring MTU.

From the third rule, it results that, in a situation when the frame in the path of lower priority coefficient starts to transmit data, competing with the frame of higher priority is ceased by modifying its speed. In formula (4.7), the theorem of triangle similarity was also used. Let *b* be the frame of lower priority competing with the frame of neighbouring MTUs of higher priority *e*.

Relating to the above rule the following formula should be used:

$$\begin{aligned} d &= \sqrt{(e.X - b.X)^2 + (e.Y - b.Y)} \\ b.vX &= b.vX + \left(\frac{(e.X - b.X) \cdot d_{\min}}{d} - (e.X - b.X) \right) \\ b.vY &= b.vY + \left(\frac{(e.Y - b.Y) \cdot d_{\min}}{d} - (e.Y - b.Y) \right) \end{aligned} \tag{4.7}$$

where: d_{min} – is defined, minimal number of jumps in the transmission path, which should not be exceeded by the transmitted frame.

Two last rules are entered to the system modifying the fourth rule, basing on relationships (4.7). It should be emphasized that each frame can move with the maximal speed imposed by the physical system. In the simulations, this speed should be limited and we should use the following:

- Limitations resulting from MTU in emergency or start up states (elements, which should be omitted by frames, creating transmission paths), and
- Attractors, in a form of main sending-receiving stations.

Summary

The concept of the method of the self-organization of the communication system enables implementing state-of-the-art and effective monitoring and control technology in underground workings, especially as regards diagnostics, monitoring, and protection of belt conveyors against fire, in which the rollers and drums, equipped with the proper electronic system, can be treated as the elements of measuring swarm. It is especially important concerning the work of people in underground facilities, where effective evacuation of people during fire is very difficult, and the fire itself can pose many other hazards. Considering the possible benefits of the application of these systems, both in terms of increased work safety and the elimination of emergencies, and their relatively low cost, it is clear that there are no significant factors that would limit the possibility of using artificial intelligence technology in mining applications.

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Samoorganizacja struktury sieciowej bazująca na algorytmie roju

Słowa kluczowe

Automatyka, metody sztucznej inteligencji, algorytmy rojowe.

Streszczenie

Zaprezentowano koncepcję metody umożliwiającej samoorganizowanie się złożonych struktur monitoringu i transmisji danych w jednolite ciągi komunikacyjne tworzące wirtualne, niezawodne medium transmisyjne. Systemy bazujące na podobnych technikach odznaczają się dużą odpornością na awarie oraz dynamiczną, samoistną zmianą struktury sprzętowej lub programowej, adaptującej się do zmiennych warunków pracy. Ze złożonymi strukturami komunikacyjnymi w górnictwie można spotkać się zarówno w przypadku transmisji głosowej, jak i transmisji danych pochodzących z układów monitoringu lub sterowania maszyn. Opisywana metoda samoorganizacji struktury wieloagentowej przygotowywana jest przede wszystkim z myślą o implementacji innowacyjnego systemu monitoringu krążników przenośników taśmowych.