OPTIMAL CONTROL SYSTEM STRUCTURE FORMATION OF HUMAN-MACHINE SYSTEMS USING GENETICAL ALGORITHMS

Huang Ruiqi, A.A. Bezrodny

Belarusian State University, Minsk, Belarus
E- mail: Ricky867626073@gmail.com

In the advancing technological era, optimizing human-machine systems is crucial for enhancing performance and user experience. The complexity of such systems and the unpredictability of human behavior present significant challenges. Genetic algorithms (GAs), inspired by biological evolution, offer a proficient method for addressing these issues by simulating natural selection processes. This enables the effective exploration of solution spaces, identifying optimal control structures for improved system performance and adaptability across various scenarios. GAs' flexibility further allows for effective solutions in diverse applications like aerospace, autonomous vehicles, and manufacturing, improving human-computer interaction.

Key words: Human-machine system optimal control; genetic algorithm; solution space; adaptability; causal approach.

ФОРМИРОВАНИЕ ОПТИМАЛЬНОЙ СТРУКТУРЫ СИСТЕМЫ УПРАВЛЕНИЯ ЧЕЛОВЕКО-МАШИННЫЕ СИСТЕМЫ С ИС-ПОЛЬЗОВАНИЕМ ГЕНЕТИЧЕСКИХ АЛГОРИТМОВ

Хуан Жуйци, А.А. Безродный

Белорусский государственный университет, Минск, Беларусь
e-mail: Ricky867626073@gmail.com, bezrodnyaa@yandex.ru

В развивающуюся технологическую эпоху оптимизация человеко-машинных систем имеет решающее значение для повышения производительности и удобства пользователей. Сложность таких систем и непредсказуемость поведения человека создают серьезные проблемы. Генетические алгоритмы (ГА), вдохновленные биологической эволюцией, предлагают эффективный метод решения этих проблем путем моделирования процессов естественного отбора. Это позволяет эффективно исследовать пространство решений, определяя оптимальные структуры управления для повышения производительности системы и ее адаптируемости в различных сценариях. Гибкость ГА также позволяет создавать эффективные решения в различных приложениях, таких как аэрокосмическая промышленность, автономные транспортные средства и производство, улучшая взаимодействие человека и компьютера.

Ключевые слова: оптимальное управление человеко-машинной системой; генетический алгоритм; пространство решений; адаптивность; причинный подход.

INTRODUCTION

This study employs Genetic Algorithms (GA), grounded in evolutionary principles, to tackle the complex optimization challenges of controlling Cyber-

Physical Systems (CPS) [1], which integrate computational algorithms and physical processes. These systems play a pivotal role in areas such as smart cities, healthcare, and manufacturing. By adopting a causal approach [2], we systematically explore the solution space for CPS control, aiming to identify optimal configurations that balance performance with adaptability. This approach emphasizes understanding the interactions between computational and physical elements, with the goal of enhancing the efficiency and reliability of CPS.

The goal of this study is to optimize the control structure of human-machine systems using genetic algorithms, in order to solve the problems of redundancy and inflexibility in current designs, thereby improving the efficiency of human-machine interaction (in the case of energy supply). To achieve the goal, the following tasks shall be solved:

1. Analyze existing research on the formation, improvement, and evaluation of control system structures to identify gaps in scope, methodology, and unexplored areas.
2. Select the most suitable software tool to construct algorithm models and workflows. Initially employing a causal approach, with the possibility of later adjustments to a more effective method.
3. Test, revise, and implement the results within petroleum supply companies.

GA MODELLING

To make the modeling more intuitive, we will use a petroleum supply company as an example for simple modeling. The design structure diagram to be incited in the modelling process is shown in fig. 1.

Allocation ratios of raw materials in refining engineering are p_1, p_2, …, p_n, where p_i represents the ratio of the i type of crude oil in the refining process. Terminal logistics management are c_1, c_2, …, c_m, representing the number of terminals. Transport route selection: Use binary variables t_{ij} to indicate whether to choose the transport route from location i to location j, where $t_{ij} = 1$ indicates selection, and $t_{ij}=0$ indicates no selection. Supply frequency and quantity of gas stations are s_1, s_2, …, s_k, representing the supply frequency of gas stations, mapped to the integer range of [1, 7]; a_1, a_2, …, a_L, representing the supply quantity of gas stations, in units of kiloliters.

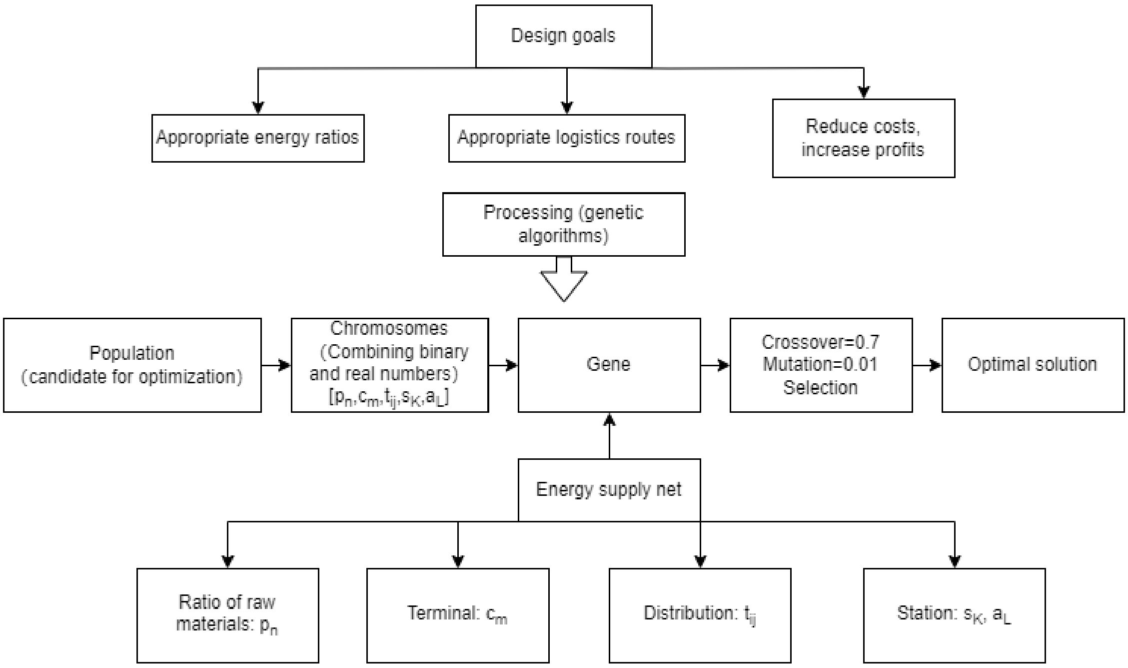

Fig. 1. Design structure diagram

Objective function (also fitness function) is defined as

$$\max_{P,C} Z \;\; = \alpha \times P - \beta \times C, \qquad (1)$$

where P – total production, where C is the total cost, where α and β are the weight coefficients.

Constraints, $\sum_{i=1}^{n} p_i = 1$, make sure all ratios notmalized to 1. The value range of raw material distribution ratio is $0 \le p_i \le 1$. The supply quantity is a non-negative number. There must be at least one terminal and one route selected.

To make a model the Roulette Selection method has been used. Roulette selection is a stochastic selection method, see in fig. 2, where the probability for selection of an individual is proportional to its fitness. The method is inspired by real-world roulettes. That means, however, that all slots have the same probability of being selected. Instead, we can implement a weighted version of the roulette. With it, the larger the fitness of an individual is, the more likely is its selection. In a population with n individuals, for each chromosome x with a corresponding fitness value f_x, we compute the corresponding probability p_x of selection (eq. (2)).

$$p_x = \frac{f_x}{\sum_{i=1}^{n} f_i} \qquad (2)$$

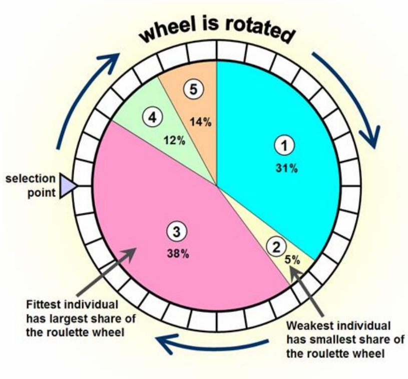

Fig. 2. Roulette Selection

In the next step we have to define the coding strategy. For optimizing a petroleum supply chain that includes refining, logistics, transportation, and supply to gas stations, the coding uses real numbers for raw material distribution ratios (e.g. 0.3, 0.2, 0.5), binary coding for logistics management and route selection decisions ([1, 0, 1] for choosing specific logistics strategies and [1, 0, 0, 1] for selecting routes), and real numbers again for the frequency and quantity of gas station supplies, like [5, 40] to indicate 40 kiloliters supplied five days a week.

SIMULATION RESUTLS

Suppose we have a medium-sized petroleum company that faces a supply problem in the following situation, see tables 1 and 2.

Table 1

Crude oil prices and refining efficiency

	Price	Refining efficiency
P1	20 USD/barrel	80%
P2	15 USD/barrel	70%
P3	30 USD/barrel	85%

Refining cost of 5 USD/barrel of crude oil and product selling price 100 USD/barrel.

Table 2

Terminal management costs and transportation costs

	C1: 1,000 USD/day	C2: 900 USD/day
G1	200 USD/barrel	200 USD/barrel
G2	150 USD/barrel	150 USD/barrel

Set the parameter values as $N = 100$, $\eta_{mut} = 0.01$, $\eta_{cross}=0.7$, $Gene = 100$. The results of the calculations are [0.598, 0.131, 0.271, 0, 1, 0, 1, 0, 0, 7, 3, 21.43, 83.3]. The maximum profit is $1284.43.

CONCLUSION

This research highlights genetic algorithms effectiveness in enhancing human-machine system controls, particularly for a petroleum supply company. GAs helped overcome design challenges like redundancy and inflexibility, significantly improving system efficiency, adaptability, and user experience. Future directions include exploring GA implementations in real scenarios, examining human factors like user acceptance, and employing more complex models (increasing the number of terminals, adding KPIs, etc.) to deepen our understanding.

BIBLIOGRAPHY

1. *Alexey Bezrodny, Anatoliy Korolenok, Aleksandr Rezchikov.* Complex human-machine petroleum system improve by causation approach // Open Semantic Technologies for Intelligent Systems. Research Papers Collection. Issue 5. Minsk, Belarus, 2021. P. 251-256.
2. *Goldberg, D. E.* Genetic Algorithms in Search, Optimization, and Machine Learning. Addison-Wesley Longman Publishing Co., Inc. 1989.
3. *Fisher, R. A.* The genetical theory of natural selection. Oxford: Clarendon Press. 1930.
4. *Kristinsson, K., & Dumont, G. A.* System identification and control using genetic algorithms. Journal of Process Control, 2(4), 1992. P. 189-204.
5. *Oliveira, Paulo, João Sequeira, and Joao Sentieiro*. "Selection of controller parameters using genetic algorithms." Engineering Systems with Intelligence: Concepts, Tools and Applications, 1991. P. 431-438.
6. *Qian Zhiqin, Teng Hongfei, Sun Zhiguo.* Genetic Algorithms in Human-Machine Interaction and Their Application in Constrained Layout Optimization[J]. Journal of Computer Science, 2001. (05): P. 553-559.