INTELLIGENT TRACKING ALGORITHMS IN COLLABORATIVE ROBOTIC SYSTEMS: APPLICATION OF CAMSHIFT AND KALMAN FILTER

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***Annotation*:** In this paper, considers modern approaches to solving the problems of tracking objects in collaborative robotic systems using intelligent algorithms. Special attention is paid to the use of the CAMShift algorithm and the Kalman filter, which are actively used to track the dynamics of object movement in various environments. The principles of operation of both methods, their advantages and disadvantages, as well as the possibilities of integration into collaborative robotics systems are analyzed. The article also contains a comparative table that summarizes the key characteristics of the algorithms and contains reflections on the prospects for their use in real-time conditions.

Key words: Industry 5.0, CAMShift, Kalman filter, cobot

Modern robotics is developing rapidly, and one of the important tasks is to ensure autonomous tracking of objects in a dynamic environment. With the development of collaborative robotic systems, where humans and robots work together, the need for accurate and fast-tracking algorithms is growing, allowing robots to respond in a timely manner to changes in the position of objects and adjust their activities. Among the many proposed methods, the CAMShift algorithm and the Kalman filter stand out. Both methods have their own specific features, which makes them appropriate for different application scenarios.

The purpose of this article is to provide a detailed analysis of the principles of CAMShift and Kalman filter operation, consider their application in collaborative robotic systems, and evaluate their effectiveness in various operating conditions. The discussion will focus on technical aspects that allow us to understand the advantages of each algorithm, as well as possible directions for their further integration into complex automatic control systems.

Intelligent tracking algorithms are an integral part of modern robotic systems, as they enable robots to recognize and track moving objects in real time. Among the numerous approaches to solving this problem, CAMShift and the Kalman filter occupy a special place due to their flexibility and high adaptability.

The CAMShift algorithm is based on the analysis of the color histogram of an object, which allows you to determine its location in the video stream. The main idea of the algorithm is to iteratively search for the center of gravity in the region of interest using the Mean Shift method, after which the size of the region is automatically adjusted according to changes in the object. This approach allows you to effectively track objects that undergo deformations or changes in size, which is important in real-time conditions, when work takes place in an unpredictable environment.

The Kalman filter is a mathematical tool for estimating the state of a system, based on a linear dynamic model. Its application is to predict the future position of an object, taking into account measurements that may contain noise. Due to its recursive nature, the Kalman filter allows for real-time estimations with high accuracy, which makes it indispensable for tasks of automatic control of robot motion in complex operating conditions.

Applications in collaborative robotic systems. Collaborative robotic systems involve close interaction between humans and robots, requiring extremely high accuracy in tracking objects and predicting their motion. In such systems, tracking algorithms are used to control manipulators, coordinate motion, and avoid collisions.

When using CAMShift, the main advantage is the system's ability to adapt to changes in the appearance of the object. For example, when the robot is working in conditions of changing lighting or in the presence of partial obscurations, CAMShift is able to quickly adjust the size of the region of interest, while maintaining tracking stability. This characteristic is especially important when performing tasks that require high flexibility, such as sorting objects on conveyor lines or in environments with unpredictable changes in parameters.

The Kalman filter, on the other hand, is notable for its ability to predict the trajectory of an object's movement. This allows not only to accurately determine the current position, but also to predict future positions, which is critically important for systems where data processing delay can negatively affect safety and efficiency. For example, in robotic systems operating in a shared space with a human, the ability to predict movement in advance allows you to avoid potential collisions and optimize movement routes.

Comparative analysis of CAMShift and Kalman filter. Both algorithms have their own characteristics that affect their application in different conditions. A comparison of the main characteristics of the algorithms is presented in Table 1.

Table 1 – Main characteristics of the algorithms.

Characteristic	CAMShift	Kalman filter
Working principle	Adaptive color histogram analysis, using the Mean Shift algorithm to determine the center of the object	Recursive system state estimation, forecasting based on linear dynamic model
Flexibility to object changes	High adaptability to changes in object size and shape	Focused on prediction, less adaptive to sudden changes
Noise resistance	Can be sensitive to changes in lighting conditions	High stability thanks to mathematical prediction model
Real-time	Suitable for tasks with high data refresh rates, but may lag under complex conditions	Provides stable real-time operation, even under conditions of high measurement inaccuracy
Resource usage	Relatively easy to implement, does not require much computing power	May require more resources to calculate predictions, especially in the case of nonlinear systems

This table clearly shows that the choice of algorithm depends on the specific requirements of the task. In situations where adaptability to visual changes is important, CAMShift may be preferred. If the main task is accurate trajectory prediction in conditions of high noise level, it is more appropriate to use the Kalman filter.

One of the key trends in modern robotics is the integration of multiple tracking algorithms to achieve greater accuracy and adaptability. The use of a combination of CAMShift and the Kalman filter allows solving typical problems of individual methods. For example, the preliminary estimate of the object position using CAMShift can be corrected using the prediction performed by the Kalman filter. This approach provides both a fast response of the system and its resistance to sudden changes and noise.

In practical applications of these algorithms, parameter settings play an important role. When using CAMShift, it is necessary to take into account the color histogram parameters, as well as environmental conditions, such as lighting and contrast. The Kalman filter requires an accurate definition of the object's motion model, which may include not only linear but also nonlinear aspects. Therefore, the integration of algorithms requires both a preliminary analysis of the system characteristics and a constant adaptation of the algorithms to changes in the working environment.

An important area of research is the application of combined algorithms in real-time. Modern collaborative robotic systems often operate in unpredictable conditions, where every millisecond can be crucial for safety and efficiency. The use of intelligent tracking algorithms makes it possible to optimize robot movement routes, quickly respond to changes in the situation and ensure high system performance. In practice, this can mean both improved production lines and increased safety in workplaces where people and robots coexist.

Experience in implementing such algorithms in various industries demonstrates that the optimal combination of CAMShift and the Kalman filter helps reduce the number of false positives of the system, and also allows you to reduce the reaction time to changes in the environment. Despite the fact that each of the algorithms has its limitations, their combined use allows you to obtain a more comprehensive solution that can take into account both the visual features of the object and the mathematical model of its movement.

CONCLUSIONS. As a result of the analysis, it can be concluded that the combined use of both algorithms allows to significantly improve the quality of tracking in robotic systems, reducing the number of false positives and optimizing the decision-making process in real time. The integration of these methods into collaborative robotics systems opens up new opportunities for increasing the level of safety, productivity and flexibility of production processes. The use of modern artificial intelligence technologies, combining different approaches to signal processing, allows to create systems that are able to adapt to constantly changing conditions and effectively cooperate with humans.

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