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THE METHOD OF OBSERVING MOVING OBJECTS

Abstract. The article analyzes known algorithms for tracking moving objects. Based on an analysis of known algorithms for tracking moving objects, it was concluded that the best tracking quality in problems with a large number of observed objects is achieved by solutions built on the basis of probabilistic and hierarchical methods. Each of them has complementary advantages, which creates prospects for creating new algorithmic solutions built on the synergy of these approaches. The main task of promising tracking methods is that they should provide ease of scaling with an increase in the number of moving objects that need to be monitored, localize objects in three-dimensional space, and also be able to work with heterogeneous sensors. This approach has both purely technical advantages and those related to the availability of microelectronics components in modern geopolitical realities.

Keywords: tracking, moving objects, pattern recognition, computing system, logical blocks.

Introduction

The rapid development of artificial intelligence technologies in recent years has significantly improved the quality of automatic image recognition, making it possible to segment complex scenes and highlight objects of interest both in the video stream and in data from other sensors, for example, scanning laser rangefinders [1–4].

This, among other things, made it possible to create local navigation systems capable of operating without the use of satellite systems, ensure identification of personnel using facial recognition, develop systems for automatically detecting emergency situations at production facilities, etc.

At the same time, in many practical tasks it is required not only to recognize the presence of this or that object, but to track and analyze the trajectory of its movement in the long term.

If an object is actively moving to cover all parts of its trajectory, it may be necessary to integrate information from several sensors [5–7]. The task becomes even more complicated when the required number of simultaneously tracked objects increases to tens and hundreds.

Main part

Promising tracking methods should provide ease of scaling with an increase in the number of moving objects that need to be tracked, localize objects in three-dimensional space, and also be able to work with heterogeneous sensors. From the point of view of tracking quality, the greatest interest is in works devoted to algorithms based on probabilistic and hierarchical methods.

Most of the studies reviewed in the literature review that had the best quality indicators were assessed using the MOTA (multiple object tracking accuracy) metric using the open APIDIS dataset.

In this regard, this metric and test data set are proposed to be used for this work.

In Table 1 presents the results of a comparison of the tracking quality of well-known algorithms that have the best tracking quality according to the multiple object tracking accuracy metric when verified on the APIDIS data set.

Table 1 – **Comparison of the quality of tracking of known algorithms when they are verified on the APIDIS data set**

Tracking algorithm	MOTA
Online Multiple Athlete Tracking with Pose-Based Long-Term Temporal Dependencies	75.2 %
Variational inference for 3-D localization and tracking of multiple targets using multiple cameras	79.6 %
Multi-camera multi-player tracking with deep player identification in sports video	81.1%
Robust, real-time 3d tracking of multiple objects with similar appearances	85.5 %
Developed algorithmic solutions	85.8 %

Estimating target localization accuracy requirements based on existing work is more challenging. The fact is that in most works, in contrast to tracking quality metrics, such data are provided. And in those works where localization accuracy is measured, it is, as a rule, assessed exclusively in the coordinate system and units of measurement of individual sensors. The latter is due to the fact that in order to assess accuracy during field experiments, it is necessary to know the exact position of all observed objects at each moment in time, which is much more difficult to ensure in practice, compared, for example, with marking data sets necessary for calculating multiple object tracking accuracy or similar metrics.

Methods for solving problems of tracking moving objects in real time.

The ability of a particular algorithm to operate in real time is determined, on the one hand, by its computational complexity, and on the other, by the performance of the computing devices on which it runs.

As practice shows, in order to achieve high performance in solving problems of tracking a large number of objects, it is necessary to use specialized hardware accelerators along with general-purpose processors.

Such accelerators, as a rule, are graphics processing units (GPUs) [8] or reconfigurable programmable logic integrated circuits [9, 10]. In addition, there are also processors equipped with specialized units to speed up and parallelize calculations.

However, from an applied point of view, such accelerators are not much different from GPUs, so in this work they will be considered together as a single group of task-oriented ultra-large-scale integrated circuits.

Fig. 1 shows a generalized block diagram of a GPU-based computing system.

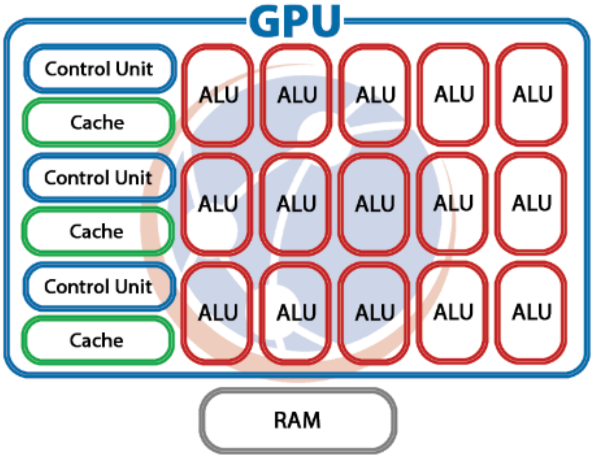

Fig. 1 Generalized block diagram of a GPU-based computing system

As you can see, the GPU includes a large number of independent arithmetic-logical units (ALUs), combined into groups that have a common control unit and cache. This structure allows you to perform a large number of calculations in parallel, significantly speeding up matrix transformations, Fourier analysis, color filtering and many others. To operate, GPU kernels require a general-purpose processor, which is typically coupled to the GPU through shared Random-access memory (RAM).

It is worth noting that this memory is one of the biggest bottlenecks when solving problems of hardware acceleration of calculations using GPUs. The fact is that, with rare exceptions, this memory is separate from the main RAM, used by a general-purpose processor to execute programs running on it. Accordingly, data loaded during the operation of these programs requires additional copying to memory associated with the GPU. As a result, if operations performed on the GPU and on a general-purpose processor are performed alternately, the time required to copy data between different blocks of memory may outweigh any benefits obtained through hardware acceleration.

Unlike a GPU, a programmable logic integrated circuit is not a complete solution, but a platform for creating specialized computing devices. It is a reconfigurable matrix of standard logical blocks that can be connected by a programmable interconnect both to each other and to the inputs/outputs of the microcircuit (Fig. 2).

A typical logic block includes truth tables and flip-flops, allowing, using their combination, to create the required hardware architecture of an implementable digital data processing unit.

Also, modern programmable logic integrated circuits can contain specialized memory units and hardware acceleration of calculations (for example, hardware multipliers or multiply-accumulate units), which significantly speed up calculations compared to their execution solely using standard logic blocks [11, 12].

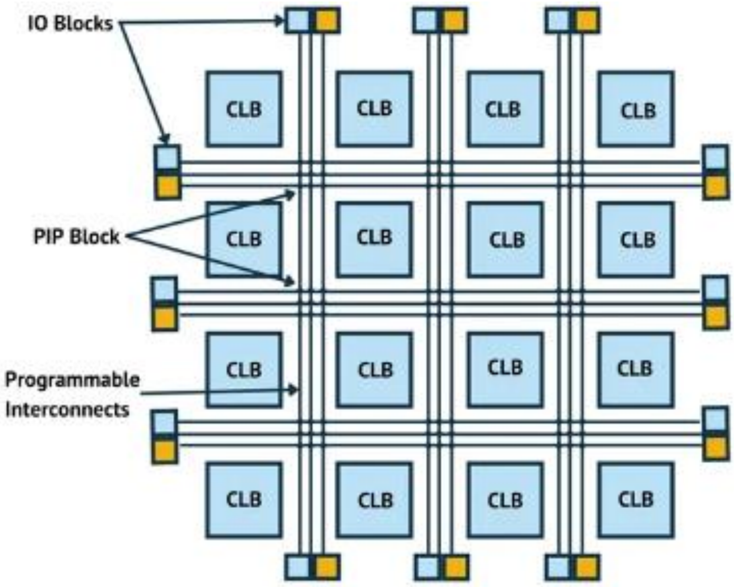

Fig. 2. Generalized block diagram of a programmable logic integrated circuit

One of the main disadvantages of a programmable logic integrated circuit compared to a GPU is the operating frequency.

Thus, many modern GPUs operate at frequencies above 1.5 GHz, providing performance of tens of TFLOPS [13]. At the same time, the clock frequencies of digital signal processing cores implemented on non-programmable logic integrated circuits rarely exceed 200 MHz, and in many cases their frequency is less than 100 MHz.

At the same time, the scientific literature has repeatedly described cases when, when solving applied problems, a programmable logic integrated circuit was superior in performance to the GPU [1? 154].

This is achieved due to the fact that on a programmable logic integrated circuit, computing cores can be deeply optimized for a specific digital data processing algorithm, while GPU ALUs were created to solve a wide range of tasks, primarily characteristic of 3D graphics visualization. As in the case of GPUs, when creating hardware computing accelerators, it is necessary to minimize data exchange with a general-purpose processor in order to avoid the influence of transport delays of the communication interface with a programmable logic integrated circuit on computing performance. At the same time, when implementing algorithms for tracking moving objects based on a programmable logic integrated circuit, it is also possible to implement the general-purpose processor itself on the same programmable logic integrated circuit as specialized computing cores [16].

This approach makes it possible to optimize data exchange between all components of a computer system, however, it is not without its drawbacks, the main one of which is the reduction in the clock frequency of a general-purpose processor to a level of 50-200 MHz, typical for solutions based on a programmable logic integrated circuit.

Table 2 shows the results of a comparison of the advantages and disadvantages of hardware acceleration of calculations based on the GPU and a programmable logic integrated circuit, obtained as a result of the analysis [17].

Table 2 – **Comparison of advantages and disadvantages of hardware acceleration of calculations**

GPU	Programmable logic integrated circuit
Advantages	
Higher performance in high-dimensional problems.	The ability to flexibly optimize solutions for a specific calculation algorithm
Developed design tools that allow you to quickly implement the necessary data processing algorithms	High performance/energy consumption ratio
Ability to operate at higher frequencies	The ability to create integrated solutions that do not require an additional microprocessor in the form of a separate chip
Lower cost with the same level of integration	Easily transfer solutions between chips from different manufacturers
Disadvantages	
Limited choice of chips, making transferring projects between them difficult	Overall complexity of the programmable logic integrated circuit hardware and software development process
Limited power optimization options	Inability to operate at high frequencies using microcircuits, with the exception of ultra-expensive solutions

As can be seen from Table 2, the main advantages of GPUs are high performance in large-scale problems and developed tools for creating the necessary software. The advantages of a programmable logic integrated circuit are: the ability to more flexibly optimize hardware solutions for the required calculation algorithm, including minimizing power consumption, the ability to create an integrated solution that does not require a separate microprocessor, and the ease of transferring created solutions between microcircuits from different manufacturers.

The latter advantage becomes especially relevant in the context of ever-increasing geopolitical sanctions, when the range of available microcircuits is not only constantly decreasing, but changing in composition over time [18, 19].

Thus, from the point of view of ensuring technological sovereignty, the use of a programmable logic integrated circuit is more promising compared to the use of GPUs. From the perspective of the general architecture of computing organization, tracking systems for moving objects can be divided into three classes: integrated, centralized and distributed.

Integrated solutions involve placing a computing device directly in the body of a particular sensor. An example of such devices are modules on the ELISE platform (Fig. 3), as well as processing units for integrated cameras based on a programmable logic integrated circuit.

Fig. 3. Computing module on the ELISE platform

The main advantage of integrated sensors is virtually unlimited access to all data combined with minimal transport delays between the measuring units and the computing device.

You can also note the ease of deployment of such systems due to the minimum number of required additional components. The main disadvantage of integrated sensors is their extremely limited scaling capabilities.

Thus, vertical scaling, as a rule, is limited by the size of the sensor, the energy resources of its power source and heat dissipation capabilities.

In addition, using integrated computing systems makes it difficult to integrate various sensory data, since in this case a fairly compact computing device must not only process large volumes of primary data, but also have the necessary volume of high-speed interfaces to receive them.

In the case of horizontal scaling, such systems move into the class of distributed computing systems [5], which will be discussed below.

Centralized systems involve processing data and implementing algorithms for tracking moving objects on a separate computing device.

Today, this is one of the most common options for systems with a large number of sensors [9].

It allows you to use the most productive multiprocessor systems by placing them in separate server racks and providing them with forced cooling. Such systems can be equipped with a large number of high-performance interfaces, including Gigabit Ethernet standards, which allows them to process and integrate a virtually unlimited number of sensors.

The main method of scaling such systems is vertical scaling, but individual components (for example, network interfaces or memory units) may allow horizontal scaling.

This explains the key disadvantage of centralized systems: they usually require decommissioning to scale up.

This requirement itself may not be acceptable for applications in the field of public safety, as well as special and military equipment.

In addition, the need to decommission systems makes it difficult to change the fluctuations in computing load over time, which is typical, for example, for traffic analysis systems [17]. The solution to this problem is the transition from centralized to distributed computing systems [7].

In distributed systems, algorithms are executed simultaneously on multiple computing devices, creating the possibility of both vertical and horizontal scaling.

Moreover, in the most advanced of them, it is possible to change the composition of computing devices "on the fly," providing both compensation for load surges over time and a high degree of equipment availability, including during repairs and routine maintenance.

A generalized block diagram of a distributed computing system for tracking moving objects is shown in Fig. 4.

Distributed systems can be built both on the basis of individual computing devices, which, among other things, process primary sensor data, and on the basis of sensors with an integrated computer [19].

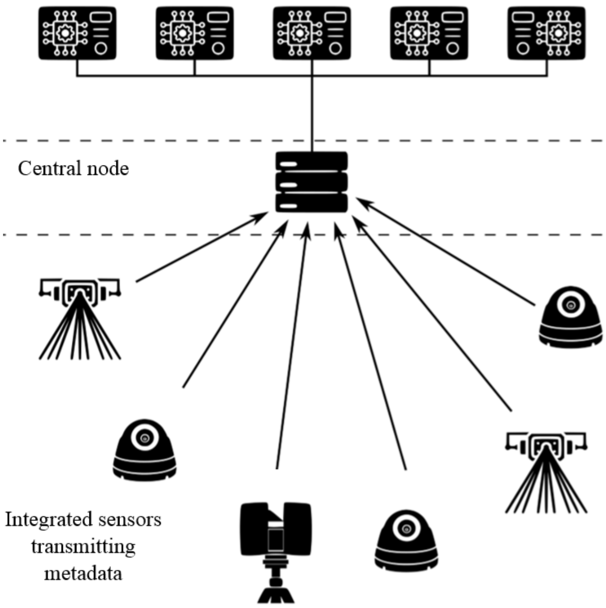

Fig. 4. Generalized block diagram of a distributed computing system for tracking moving objects

In the latter case, it seems promising to use the sensor's on-board computer for primary processing of its information, performing segmentation and pattern recognition procedures, the output of which will generate metadata about each of the selected objects.

Next, this metadata will be transmitted via communication channels to distributed computing nodes, which, based on it, will provide a comparison of objects isolated from the data of various sensors with each other and predict their trajectory.

This approach has successfully proven itself in robotics.

It allows you to significantly reduce the throughput of communication channels and at the same time ensure overall high reliability of the end system.

Moreover, by reducing traffic from the sensors used to simplify implementation, it can have a central node that will distribute the most resource-intensive calculations and manage data flows in the system.

Conclusions

Based on an analysis of known algorithms for tracking moving objects, it was concluded that the best tracking quality in problems with a large number of observed objects is achieved by solutions built on the basis of probabilistic and hierarchical methods. Each of them has complementary advantages, which creates prospects for creating new algorithmic solutions built on the synergy of these approaches. An analysis of known methods for ensuring the operation of real-time tracking systems has shown that the most promising way to achieve the goal of this work is the creation of algorithms that can be executed in the architecture of a distributed computing system based on hardware accelerators implemented using a programmable logic integrated circuit. This approach has both purely technical advantages and those related to the availability of microelectronics components in modern geopolitical realities.

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Метод спостереження за рухомими об'єктами

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Анотація. У статті проведено аналіз відомих алгоритмів стеження рухомих об'єктів. На основі аналізу відомих алгоритмів відстеження рухомих об'єктів зроблено висновок, що найкраща якість відстеження в задачах із великою кількістю спостережуваних об'єктів досягається рішеннями, побудованими на основі імовірнісних та ієрархічних методів. Кожен з них має взаємодоповнюючі переваги, що створює перспективи для створення нових алгоритмічних рішень, побудованих на синергії цих підходів. Головне завдання перспективних методів стеження полягає в тому, що вони повинні забезпечувати простоту масштабування зі збільшенням кількості рухомих об'єктів, за якими необхідно стежити, здійснювати їх локалізацію об'єктів у тривимірному просторі, а також мати можливість роботи з різнорідними сенсорами. Такий підхід має як суто технічні переваги, так і пов'язані з доступністю компонентів мікроелектроніки в сучасних геополітичних реаліях.

Ключові слова: стеження, рухомі об'єкти, розпізнавання образів, обчислювальна система, логічні блоки.