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# Smart traffic lights with video vision based on a control minicomputer in Kazakhstani megacities

Baurzhan Belgibaev[a], Madina Mansurova[a]*, Sanzhar Abdrakhim[b], Ainur Ormanbekova[a]

[a] *Al-Farabi Kazakh National University,* Al-Farabi ave., 71, *Almaty* 050040*, Kazakhstan*
[b] *Hong Kong Polytechnic University, M1504, Li Ka Shing Tower, Hunghom, Kowloon, Hong Kong*, *China*

**Abstract**

This article proposes innovative solutions in the field of traffic management – smart traffic lights with computer vision, aimed at improving traffic flow in the large cities of Kazakhstan. With a growing number of vehicles and increasing traffic volume, the issues of congestion and delays at intersections have become increasingly relevant. The article reviews the operational principle of such smart traffic lights, which is based on analyzing computer vision data using sensors and cameras. The benefits of applying this technology, including responsiveness, efficiency, and environmental friendliness, are considered. Furthermore, the potential of smart traffic lights in major megacities of Kazakhstan, such as Astana and Almaty, is analyzed in detail. The conclusion supports the assessment of traffic flow, travel time, and an overall evaluation of the traffic situation. Ultimately, this article highlights the improved performance of smart traffic lights with computer vision coverage in modern cities of Kazakhstan, aiming to ensure higher traffic safety and efficiency.


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*Keywords:* *Automation of the movement of traffic flows, traffic light with video vision, intelligent control systems, smart traffic light as a neurophysical device.*

* Corresponding author. Tel.: +77014151960;
*E-mail address:* madina.mansurova@kaznu.edu.kz

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## 1. Introduction

Modern IP video cameras are integral to various devices, with miniaturization and increased resolution. They find application in transport traffic management, nuclear reactor inspection, spacecraft, and launch vehicles.

Electric cars are equipped with multiple video cameras for creating a 3D road picture, enabling autonomous autopilots. Neural networks are often implemented on powerful PCs, but compact minicomputers like Raspberry Pi 4 handle mobile traffic light recognition and traffic control.

Processing extensive data in transportation necessitates innovative mobile control minicomputers. While challenges arise when transferring solutions to single-board minicomputers, their GPIO libraries and control boards are beneficial for embedded systems.

Industrial automation often relies on stationary PCs, but there's a shift towards mobile utilization of neural networks, requiring specialized training methods for mini computers.

The Raspberry Pi 4 Model B is used in integrated control systems for smart traffic lights. The preference is for higher CPU core clock frequencies, larger RAM, and increased video memory. There's rapid advancement in both software and hardware for embedded control minicomputers [1].

These advancements can help solve urban traffic regulation problems, including data collection on license plates and seat belts.

Automating traffic regulation in Kazakhstani cities like Astana and Almaty is socially significant and enhances the image of modern smart metropolises.

## 2. Materials and methods

Let's consider the cause-and-effect relationships that led to the development, construction and implementation of smart traffic lights with video vision into the practice of traffic police in Kazakhstan's megacities.

The city of Almaty, and later the new capital of the Republic of Kazakhstan Astana, has a complex and complex road network design. Historically, it developed mainly due to the rectangular design of roads and streets, and in some areas of the city, a combined highway network and residential buildings (see Figure 1). This structure of the city has led to a significant increase in the intersection of highways, the movement of which is currently regulated by traffic lights.

a b

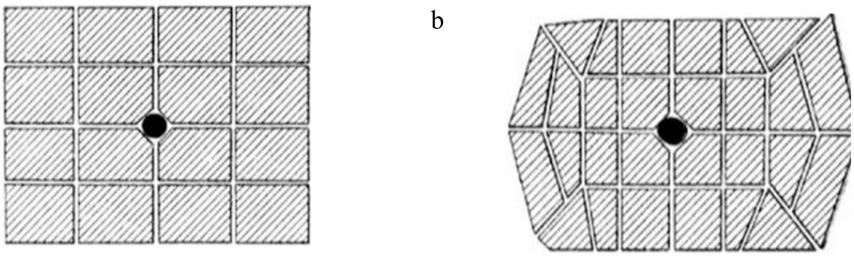

Fig. 1. (a) Rectangular; (b) and combined road network of the city of Almaty.

The city of Almaty stands out as a modern megacity lacking a developed network of ring roads free from traffic lights. In contrast, cities like Beijing, the capital of China, boast a well-established network of ring roads (as seen in Figure 2a). In Figure 2b, transportation routes are organized following the principle of 'point A - ring road - nearest radial road - point B' [2].

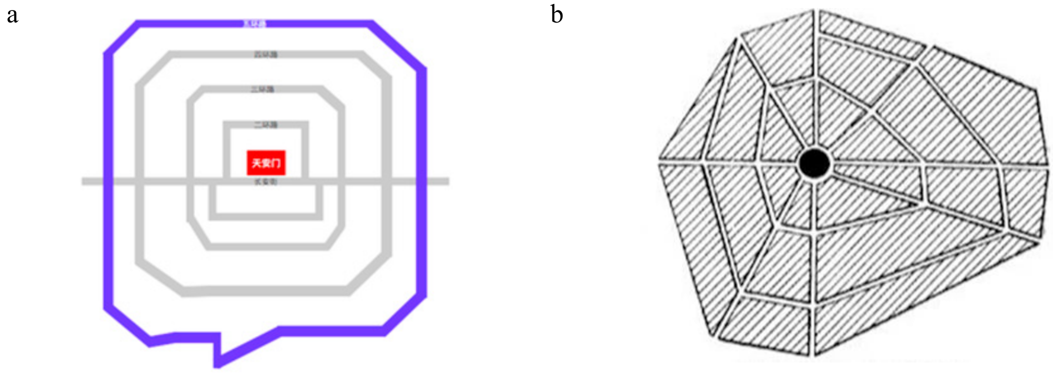


Fig 2: Main Types of Urban Highways: (a) Beijing Ring Highways (b) Radial-Ring Highways of Paris, Vienna, Moscow, etc.

In Almaty, due to its foothill location, the mountain rivers Malaya Almatinka, Esentayka, Big Almatinka and other rivers, which are located in the residential areas of the city, flow through the city center from south to north. The road network in Almaty combines rectangular streets with residential areas. Traffic accumulates on highways, leading to congestion in the city center due to limited bridge crossings, which we see as the central transportation issue.

In the city center, limited bridge crossings cause traffic to concentrate on main highways. This leads to periodic congestion when east-west highways intersect with north-south traffic. Traffic lights control these highways with fixed signal phases, and during rush hours, traffic police manually regulate traffic, playing a vital role in managing transportation in the city center. As an illustrative example, let's examine the operation of traffic lights at the intersection of Sain Avenue and Abay Avenue during rush hours [3].

The concentration of cars on Abai Avenue is explained by the fact that this highway is the shortest road to the city center. In the "green wave" mode, this distance can be covered in 20-25 minutes. In reality, during rush hours the travel time will be from 45-60 minutes depending on the weather and road conditions. A traffic police officer visually oversees the leading and trailing vehicles in queues before and after the traffic light. When the convoy starts moving, the officer signals to keep the traffic flowing until the convoy's speed diminishes. In automatic mode, the traffic light cycle is 40 seconds on Abay/Sain and 90 seconds on Abay/Altynsarin. This system maintains smooth traffic flow during regular times. Ideally, this cycle ratio avoids congestion or very slow traffic. If issues arise, a traffic police officer intervenes to prevent complete traffic disorganization and potential traffic jams).

The traffic controller's role is to prevent traffic jams. Intelligent control follows fuzzy logic requirements, allowing for smart traffic lights. A microcontroller, a video-enabled minicomputer, handles tasks such as monitoring car counts, adjusting traffic light phases, notifying adjacent lights and car numbers, measuring traffic speed by time and season, and continually updating the ATCS database. Existing video-equipped minicomputers enable the creation of an Automated Traffic Control System (PAO) utilizing the built-in Intelligent Management System (IMS) in standard traffic lights at intersections in Almaty and Astana's megacities [4].

## 3. Research results and discussion

The crucial step in developing a functional prototype of a smart traffic light with video vision is the optimal selection of the circuit design for the integrated Intelligent Traffic Light System. Figure 3 presents a functional diagram illustrating the interface of a smart traffic light powered by a LOGO8 microcontroller, 230 RCE. Further details on the enhancement of the traffic light controller DK 2 with this microcontroller are provided in [5].

As can be seen from Figure 3, the electrical circuit of the neural vision of a smart traffic light has changes compared to previously developed smart traffic lights with QR code recognition of special vehicles. Instead of the IoT microcontroller ESP 32 Cam, a control minicomputer Raspberry Pi4/ Model B/ RAM 8Gb is used. This improvement requires increasing the power of the low-voltage circuit at 5VDC to 50 watts, the circuit at 220VAC powers the

LOGO8!230RCE web microcontroller and the traffic light. The peculiarity of the electrical circuit is that the low-voltage circuit must have a common "GND" [6].

Let's delve into the process of activating the green light on the traffic signal after analyzing the traffic situation using the smart traffic light's vision system along the western side of Abay Avenue, as depicted in Figure 3. The video camera employs the YOLO neural network CNN application from the CV2 library, installed within the Python 3 environment of the Raspberry Pi 4 minicomputer, to assess the number of vehicles in a three-lane queue.

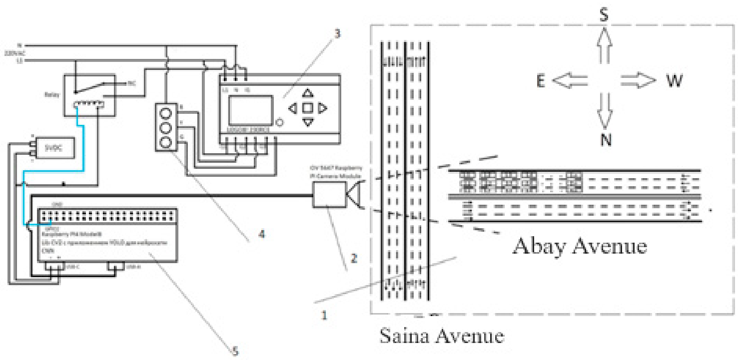


Fig. 3. Functional electrical diagram of the built-in IMS of a smart traffic light: 1 - video surveillance object (crossroad at the Abay-Sain junction); 2 – USB webcam with autofocus and infrared illuminator, 3 – LOGO8!230RCE travel microcontroller, 4 – traffic light, 5 – Raspberry Pi4/RAM 8Gb/1.2 GHz control minicomputer.

As noted above, solutions to similar problems are available for stationary PCs. Therefore, it is not correct to claim that the code is simply transferred from a PC with Win 10 OS to Linux OS for the Raspberry minicomputer [7].

Additional challenges when writing and debugging the traffic light control code include the use of the GPIO Python 3 library. This library allows you to transmit a control electrical signal to a relay coil, initiating the switching of a road traffic light controller based on the LOGO8!230RCE microcontroller to the green state. The code for the traffic light control program, which relies on the signal from the input sensor I1 of the road controller based on the LOGO8!230RCE MK, can be found in [8].

A positive signal on pin I1 shifts the traffic light from a fixed phase mode to an adaptive mode. In the adaptive mode, the right traffic light displays yellow for 5 seconds, followed by green until the car count falls below N=50. Initially, the traffic light timer allows a maximum of 40 seconds for adaptive operation, relieving congestion on the side roads for left turns from Saina Avenue. In the fixed mode, 70 seconds are allocated for oncoming traffic, and 20 seconds for left turns, which is often insufficient even during regular hours. These settings are preliminary and subject to adjustment based on video and statistical data from the project. Future work in the Any Logic PLE environment will focus on simulation calculations to optimize the timing between green and red traffic light phases at this junction [9]. Thus, the main detector device of the built-in system being created is a web camera with autofocus and an infrared night illuminator. The smart camera is connected via a USB connector to an IoT neurophysical device in the form of a single-board control PC, which converts the real image into some multidimensional matrix with a density of 5M pixels. Raspberry Pi Camera Module OV 5647 allows you to digitize and pre-process images with extraordinary characteristics. Thus, the Arducam 5MP OV5647 Motorized IR-CUT module conducts operational video shooting in daylight, and forms night video images using an automatic infrared spotlight. This series of video cameras is fully software and hardware compatible with Raspberry Pi interfaces from the Pi Zero series to Pi 3, Pi4. hen the camera is stationary, the PAO functions as a motion sensor by detecting changes in the image. To conserve resources, it continuously updates the background image with new changes in the dynamic video image. These features are achieved without requiring additional configurations, using standard Python 3 libraries like those for mathematical operations (matplotlib, numpy), and image processing (skimage). This solution can be effectively applied in the context of implementing smart cameras on mini-computers and microcontrollers. This "smart filter" significantly reduces server traffic, compressing the original 1 MB image to 0.6 MB [10].

Using the following notation of the program code algorithm for Python 3 OS Linux Raspberry Pi4/ RAM 8 Gb, the functionality of counting the number of cars in the right lane along Abai Avenue from a video image is implemented. This code opens up new prospects for improving video recognition algorithms in transport.

The algorithm in code notation consists of the following steps:

Beginning =># Initialize the libraries =># Create a function to draw rectangles with text at specific coordinates =># Initialize the necessary variables =># Determine the minimum car count to trigger a green light =># Initialize the names of all recognition classes using YOLO# => # Randomly assign colors to each object class =># Set up the camera using cv2=># Configure the YOLOv8n recognition model=> # Initialize the font using cv2=> #Capture an image from the camera=>#Determine the maximum dimension between height and width=> #Convert the image into a 640x640 array of values between 0 and 1=> #Process the image based on its dimensions=> #Apply non-maximum suppression to identify relevant entities=> #Store detection data, including object index, name, confidence, coordinates, and degree of reduction=> #Draw rectangles around detected objects=> #Resize the image for convenience (not the recognized image) => #If the car count exceeds a set threshold, activate the traffic light=> #Free up memory and end the program.

Note that the complete free working code of the program can be found at the link [11]. The neurovision program for a smart traffic light is maximally structured, reliably recognizes and calculates the traffic situation in the city of Almaty (see Figure 4). The code will be modernized in the future for a number of new recognition tasks, such as identifying car license plates, searching for cars by a certain characteristic (color, body type, regional location of state registration, etc.). This suggests that the development and training of an intelligent traffic light with video vision will be ongoing and will bring it closer to the capabilities of a human traffic controller. Thus, visual monitoring of congestion in the right lane of vehicles is entrusted to an intelligent video camera, which automatically determines the congestion of the intersection and turns on the green light of the traffic light. Currently, the Abay-Saina intersection operates from a traffic light with fixed phases of red-yellow-green signals.


Fig.4. (a), (b) Video recognition of the traffic situation at the intersections of the city of Almaty; (c) the operation of the Raspberry Pi4 low-voltage circuit depending on the number of recognized vehicles

This traffic light mode leads to the fact that on the side roads adjacent to the Abay-Saina interchange, large columns of cars are lined up, which do not have time to make left turns at least from the third traffic light cycle. Reducing the operating time of the adaptive traffic light for direct travel from west to east and vice versa will reduce the traffic load at the Abay Sain interchange [12].

The proposed prototype and program code significantly increases the functionality of a smart traffic light by expanding the tasks of recognizing license plates, determining the degree of congestion of central streets with cars from suburban areas, etc. [13]. These options will be opened as research expands and will certainly make it possible to create a developed adaptive system for controlling traffic light objects, which, if possible, will repeat and even slightly exceed the functionality of a traffic policeman.

## 4. Conclusion

This study focuses on the city of Almaty and may require further adaptation when applied to other cities or regions. The developed prototype and program code are based on modern technical solutions, such as Raspberry Pi. The use of this technology may be limited in regions with limited access to modern computing resources. Research results may depend on the availability and quality of data used for neural network training and simulation.

Comparison with existing motion control methods and technical solutions:

- The approach based on intelligent neuro-physical devices with video vision represents an innovation in the field of artificial intelligence motion control. Compared to traditional traffic signal control methods, this approach allows for more efficient response to changing traffic conditions.
- Analysis of the algorithms used by police officers for manual traffic control confirms the possibility of automating these processes using modern microprocessor neuro-devices. This represents a significant step towards more efficient and accurate motion control systems.
- In terms of comparison with existing similar approaches, the proposed mobile adaptive traffic light with neuro video vision has a high degree of automation and the ability to respond to congestion and traffic situations. This can make it more efficient than traditional static traffic lights.
- It is important to note that this study is limited by local context and technical limitations, and its effectiveness may vary depending on location and available resources. Additional research and adaptation may be required for successful implementation in other regions.

The study shows the potential for developing smart traffic lights into neuro-physical devices with video vision that can more effectively regulate traffic. Additional research and adaptations could make this technology more accessible and effective in different cities and regions.


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