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OVERVIEW OF MOTION AND PRESENCE DETECTION SYSTEMS USED IN SMART LIGHTING SYSTEMS

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The article describes stages of design of smart lighting systems. Advantages and disadvantages of detectors used in smart lighting systems are stressed with the purpose of further development of these systems. Ambient factors, which affect the detection system, were analyzed and consequent conservation measures were proposed.

Key words:
Smart lighting system, motion detectors, presence detectors, ambient factors, image recognition

Introduction

The smart lighting system considered in the article is a system of efficient city street lighting, which can significantly reduce energy costs by connecting each lamp to the network and controlling its state (on / off), depending on the movement of pedestrians and vehicles.

In conditions of the widespread increase in energy costs, the application of these systems will not only increase efficiency, but also partly solve the problem of resource efficiency of technologies in the modern world.

Benefits of smart lighting systems over the common ones are:

- standard lighting systems provide lighting that does not depend on both the actual time of daylight and weather conditions, which can be simply solved by a smart lighting system when using this dependence and taking appropriate actions;
- switching on and off of the lighting systems currently in use does not depend on the presence of pedestrians and moving cars, therefore energy can be wasted for a long time [1].

It is obvious that the application of this technology in city lighting will exclude the issues of increasing the number of power plants and energy shortages. The effect of using smart lighting systems is enormous, taking into account that one fifth of all electricity in the world is consumed by city lighting.

The article reviews the methods of motion and presence detection with reference to possible implementations of smart lighting sensor systems that are the basis of the entire lighting system.

Structure of smart lighting systems

A lighting system is a combination of a central unit and streetlights connected to it (Figure 1).

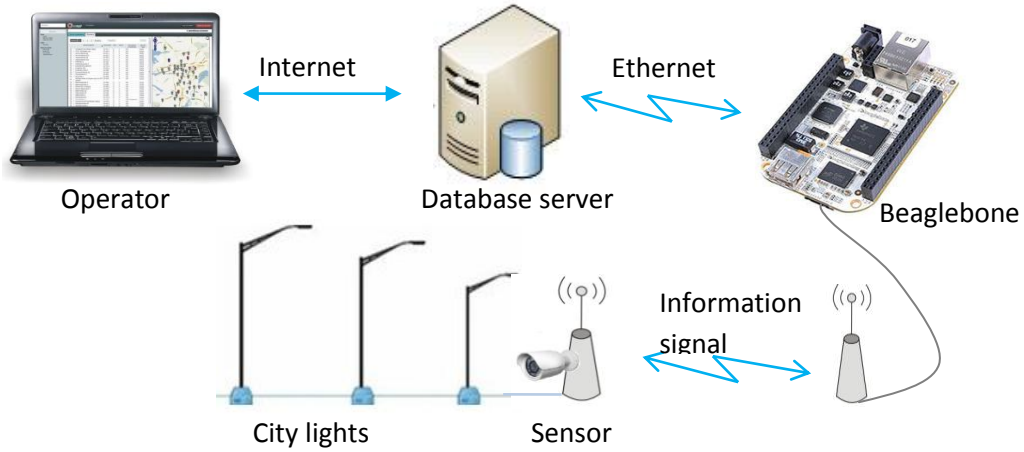

Fig.1. Structure of smart lighting systems

The central control unit is a Beaglebone minicomputer. Each lamp has systems of communication and detection. The first system is used for communication with the Beaglebone, the second one detects a controlled object (a passing-by pedestrian). When a pedestrian enters the control zone, the signal goes to Beaglebone, which will enable lighting close to the pedestrian.

In accordance with the hardware, the corresponding software is used. The developed program is executed by Beaglebone, which supplies appropriate control signals to the lights. The complexity of this is to create a reliable method for detection of a moving or static object. Nowadays, the level of development of motion sensors used in lighting systems challenges to investigate new ways of detection. Sensors currently in use are often falsely triggered and mistakenly stop working when a moving object stops. A solution to this problem can be found using the combination of sensors and improving the data processing algorithms.

After processing, the data arrive at the database server and can be seen and controlled by the operator.

Movement and presence detection methods. Acoustic (ultrasonic)

The principle used in acoustic sensors is the principle of active location, i.e. scanning the space (zone of control) by sound waves in the ultrasonic range. Parameters of received waves are continuously monitored by the sensor.

Ultrasonic waves are elastic mechanical waves propagating in air. The appearance of a person in the zone of control causes a change in the characteristics of the ultrasonic waves. This happens due to the known physical effects such as reverb, diffraction, interference, Doppler effect, and others [2].

An ultrasonic field may be generated by pulsed or continuous waves (without modulation or with amplitude modulation and/or frequency) [2]. Motion detection may be based on an analysis of parameters of sent and received ultrasonic waves, such as difference of amplitudes, frequencies, and time characteristics. Also, there are sensors in which the transmitter and the receiver are mounted opposite to each other. When the ultrasonic wave is interrupted by an object, a signal to perform a function is triggered. More advanced volumetric detectors use a set of information attributes that are processed by a certain algorithm.

The most widely used sensors are based on the Doppler effect, according to which the frequency of an ultrasonic signal reflected from a moving obstacle differs from the original by an amount directly proportional to the transmitted frequency and the radial velocity of the reflector, and is inversely proportional to the velocity of propagation of ultrasound in the zone of control. This value will be positive if the radial component of motion of the reflector is directed towards the source of ultrasound (when approaching the sensor), and negative in the opposite case (when leaving the sensor). In case of change of frequency of the reflected signal from the moving objects is detected, the sensor performs its function.

By means of a piezoelectric element generates waves with a frequency from 20 kHz to 60 kHz, which are transmitted to the zone of control and, reflecting from the surrounding objects, come back to the piezoelectric element.

When a moving object appears in the zone of control of the ultrasonic motion sensor, the frequency of the wave reflected from the object is changed (Doppler effect), which is registered by the receiver and then the sensor performs its function [3].

Sensors of this type have the following advantages:

- low cost;
- they are hardly affected by ambient conditions;
- they can determine movement regardless of the material of the object;
- the effect of air flows with the speed up to 10 m/s on the sensors is negligible.

However, there are the following disadvantages:

- low operating range;
- they only respond to sharp moves – if the movement is smooth, it is possible to fool an ultrasonic motion detector;
- temperature and humidity affect the speed of sound. The increase in air temperature significantly affects the accuracy of the response.

Radio wave (microwave)

The principle of operation of these sensors is based on the interference of radio waves in the centimeter range or, in other words, the Doppler effect. Radio waves from the device reflect from a moving object and are changed with its length or frequency. After reflection from the object, a radio wave is sensed by the device. Further actions of the sensor are determined by certain sensor properties and the algorithm: either an alarm signal is formed and sent to the receiver, or the received radiowave with altered characteristics is ignored (if the parameters of fixed object do not match). Modern motion sensors used in security are protected against false alarms, such as movement of single small animals or birds [4].

Each detector comprises a microwave unit, which consists of a transmitter and a receiver of high frequency oscillations. Radiowave detectors are active devices that transmit microwave oscillations [5].

The source transmits high-frequency electromagnetic waves (usually from 5 to 8 GHz), which are reflected from the surrounding objects and registered by the sensor. The resulting signal is amplified and filtered to exclude registration of objects moving either too slowly or too quickly. The only allocated speeds are from 1 to 5 km/h, which are appropriate to the motion of people. Mixer diode adds transmitted (reference) and reflected waves.

This type of sensor has the following advantages:

- it is able to detect objects beyond different insulation or weakly conductive obstacles: thin walls, doors, windows, etc.;
- sensor performance is not dependent on ambient temperature or objects;
- it is able to respond to the slightest motion of the object;
- it may have several independent detection zones.

Also there are some disadvantages:

- higher cost relative to other types of sensors with similar parameters;
- there is a possibility of false responses due to movements outside the required zone of control; such sources of false responses may be, for instance:
  - mounting fixtures of fluorescent lamps;
  - operating electrical equipment, creating a vibration;
  - small animals and birds;
- microwaves are dangerous for human health, therefore it is necessary to choose the microwave motion sensors with low power, which are safer for people and have the power density of 1 mW/cm^2.

Infrared sensor

The operating principle is based on registration of infrared (IR) emission changes caused by the movement or presence of people. After contacting with the infrared lens, the photocell changes its parameters. The intensity of infrared emission depends on the temperature of the body, which is brighter at higher body temperatures in infrared waves.

When the object moves, the infrared emission is focused alternately by different lenses of the sensor (the number of lenses typically varies from twenty to sixty pieces), this is a signal to perform the functions built in the sensor. The more lenses are built in the system of the motion sensor, the higher the sensitivity is. Also the larger the surface area of the lens system is, the broader the area of coverage of the motion sensor is.

Infrared motion sensors can be divided into motion detectors and presence detectors by the degree of sensitivity. Motion sensors are less sensitive and amplification path of photocell is limited in thermal sensitivity. Presence sensors are able to respond to the slightest movement. Nowadays, almost all sensors of both movement and presence are sensors with a circular or oval detection diagrams. Presence sensors with square detection area are not widespread now because of their cost. The square detection area simplifies the design and also requires far fewer sensors to monitor a certain area [6].

The advantages of infrared sensors include:

- ability to adjust the distance and angle of detection of moving objects;
- they are absolutely safe for human and animal health, as they work as receivers, emitting nothing.

But there are some disadvantages:

- the possibility of false responses due to the IR sources, which include warm air, cars, sunlight, and rainfall;
- relatively small range of operating temperatures.
- they do not detect objects covered in IR resistant materials.

Taking into account the characteristics of the infrared sensors, the implementation of a lighting system using infrared sensors for automated control is problematic and is possible only when combining with other types of sensors that reduce the negative effects from the infrared sensors.

Visual method

Development of technologies in video recording and processing enables using video not only in the cases, which are aimed at video technology, such as recording and playback of video, but also in non-obvious cases: for example, use of video cameras as smart sensors. Widespread cameras are used to detect motion of objects in modern cars' safety systems for greater automation of the movement process and safety [7-8]. Nevertheless, video camera as an intelligent sensor for lighting systems is almost never used. The development of advanced data processing algorithms provides an opportunity to design such systems [9].

To identify the controlled objects' combinations of points obtained in the video frame processing are used and form criteria for such an identification (Figure 2).

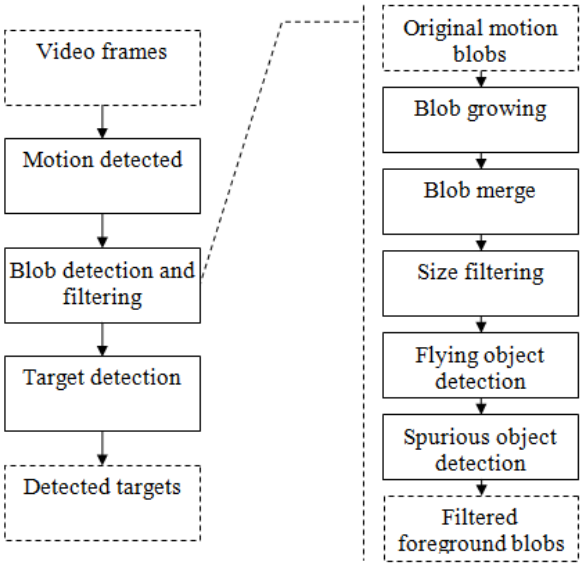

Fig.2. Diagram of the video processing system

Data obtained from the camera are processed by specialized algorithms. In the used algorithm, the video frame is divided into blobs that are classified, filtered, and form some combination that characterizes the specific property of the identified object. As a result of finding the desired object, a signal is supplied to perform further functions.

Advantages of the visual method:

- control of larger space, in contrast to other methods;
- identification not only of motion but also of the presence of the object;
- low probability of false responses.

Disadvantages of this method are:

- complexity of data processing algorithms;
- dependence on light, which can be compensated with an infrared filter.

Visual method can be widely used on road sections where cameras are already in operation, which enables reducing the cost of implementing smart lighting systems. High resolution of modern cameras makes it possible to use one camera instead of several sensors on the same stretch of road.

Combined control methods

The basic methods of motion and presence detection have both advantages and disadvantages. Generally, these disadvantages are associated with the failure of the sensor to detect a person in certain conditions or, alternatively, its false response.

Using a combination of methods for monitoring and detection can significantly reduce the likelihood of incorrect performance of the sensor. An alarm signal is generated only if both detectors are activated simultaneously or within a short time interval. To increase the stability of the system, it should be considered that the interferences causing false alarm signals should affect each detector differently. Table 1 shows the impact of external factors on the operation of sensors of different types.

Table 1. Sensitivity of the sensors to external factors

Ambient factor	Infrared	Microwave	Ultrasound	Visual
Air turbulence	+	-	-	-
Changes in temperature	+	-	+	-
Bright light	+	-	-	+
Electromagnetic interference	+	+	-	+
Fluorescent lighting	-	+	-	-
Vibration	+	+	+	-
Moving outside the control zone	-	+	-	-
Animals	+	+	+	-

The table shows that the majority of ambient changes have different effects on each detector and in most cases can not lead to simultaneous activation of both sensors.

The most widely used combination at present is a combination of microwave and infrared detection principles. Much less often, a combination of ultrasound and infrared detectors is used. There are also some examples of sensors that use three different physical principles of detection, but such sensors are almost never used [10].

Conclusion

Use of the designed system is a distinct addition to pedestrian and transportation networks of the city. In modern cities, especially in Russia, the development of pedestrian areas requires infrastructure that is offered in our project.

The factor of resource efficiency in modern technologies is vital. Especially, the question of energy consumption reduction becomes increasingly important in the period of crisis, thus, use of smart lighting systems will significantly reduce energy consumption.

In the paper, centralized smart lighting system was considered. The structure of the system with elements and devices inside are considered, and the principle of work is described as well. The present study emphasizes motion detection methods in the control area because this is the stage when signals are formed and affect the efficiency of the entire system. Currently, correct work of the sensors of a smart lighting system, i.e. providing a high probability of response and stability of the system, is a big problem due to presence of certain unfavorable conditions and confounding factors.

Using the most advanced methods for motion and presence detection enables increasing the stability and reliability of a system. Today, smart lighting systems can achieve high detection accuracy and, consequently, correct work is gained only in the case of using visual and combined methods of detection.

On the basis of the considered methods and developed efficient algorithm of signal processing and controlling, which are applied from detectors by the microcomputer, highly precise, resource-efficient, and stable smart lighting systems can be designed.

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