The author is indebted to the supervisor of this thesis, ***doc. Ing. František Zbořil, CSc.*** *for his great help.*

THIS WORK IS A PART OF THE RESEARCH PLAN "SECURITY-ORIENTED RESEARCH IN INFORMATION TECHNOLOGY, MSM 0021630528" AT BRNO UNIVERSITY OF TECHNOLOGY

1.1 ANPR systems as a practical application of artificial intelligence

Massive integration of information technologies into all aspects of modern life caused demand for processing vehicles as conceptual resources in information systems. Because a standalone information system without any data has no sense, there was also a need to transform information about vehicles between the reality and information systems. This can be achieved by a human agent, or by special intelligent equipment which is be able to recognize vehicles by their number plates in a real environment and reflect it into conceptual resources. Because of this, various recognition techniques have been developed and number plate recognition systems are today used in various traffic and security applications, such as parking, access and border control, or tracking of stolen cars.

In parking, number plates are used to calculate duration of the parking. When a vehicle enters an input gate, number plate is automatically recognized and stored in database. When a vehicle later exits the parking area through an output gate, number plate is recognized again and paired with the first-one stored in the database. The difference in time is used to calculate the parking fee. Automatic number plate recognition systems can be used in access control. For example, this technology is used in many companies to grant access only to vehicles of authorized personnel.

In some countries, ANPR systems installed on country borders automatically detect and monitor border crossings. Each vehicle can be registered in a central database and compared to a black list of stolen vehicles. In traffic control, vehicles can be directed to different lanes for a better congestion control in busy urban communications during the rush hours.

1.2 Mathematical aspects of number plate recognition systems

In most cases, vehicles are identified by their number plates, which are easily readable for humans, but not for machines. For machine, a number plate is only a grey picture defined as a two-dimensional function $f(x, y)$, where x and y are spatial coordinates, and f is a light intensity at that point. Because of this, it is necessary to design robust mathematical machinery, which will be able to extract semantics from spatial domain of the captured image. These functions are implemented in so-called "ANPR systems", where the acronym "ANPR" stands for an "Automatic Number Plate Recognition". ANPR system means transformation of data between the real environment and information systems.

The design of ANPR systems is a field of research in artificial intelligence, machine vision, pattern recognition and neural networks. Because of this, the main goal of this thesis is to study algorithmic and mathematical principles of automatic number plate recognition systems.

Chapter two deals with problematic of number plate area detection. This problematic includes algorithms, which are able to detect a rectangular area of the number plate in original image. Humans define the number plate in a natural language as a "*small plastic or metal plate attached to a vehicle for official identification purposes*", but machines do not understand this definition. Because of this, there is a need to find an alternative definition of the number plate based on descriptors, which will be comprehensible for machines. This is a fundamental problem of machine vision and of this chapter.

Chapter three describes principles of the character segmentation. In most cases, characters are segmented using the horizontal projection of a pre-processed number plate, but sometimes

these principles can fail, especially if detected number plates are too warped or skewed. Then, more sophisticated segmentation algorithms must be used.

Chapter four deals with various methods normalization and detection of characters. At first, character dimensions and brightness must be normalized to ensure invariance towards a size and light conditions. Then, a feature extraction algorithm must be applied on a character to filter irrelevant data. It is necessary to extract features, which will be invariant towards character deformations, used font style etc.

Chapter five studies pattern classifiers and neural networks and deals with their usage in recognition of characters. Characters can be classified and recognized by the simple nearest neighbor algorithm (1NN) applied to a vector of extracted features, or there is also possibility to use one of the more sophisticated classification methods, such as feed-forward or Hopfield neural networks. This chapter also presents additional heuristic analyses, which are used for elimination of non-character elements from the plate.

Sometimes, the recognition process may fail and the detected plate can contain errors. Some of these errors can be detected by a syntactical analysis of the recognized plate. If we have a regular expression, or a rule how to evaluate a country-specific license plate, we can reconstruct defective plates using this rule. For example, a number zero "0" can be automatically repaired to a character "O" on positions, where numbers are not allowed. Chapter six deals with this problematic.

1.3 Physical aspects of number plate recognition systems

Automatic number plate recognition system is a special set of hardware and software components that proceeds an input graphical signal like static pictures or video sequences, and recognizes license plate characters from it. A hardware part of the ANPR system typically consists of a camera, image processor, camera trigger, communication and storage unit.

The hardware trigger physically controls a sensor directly installed in a lane. Whenever the sensor detects a vehicle in a proper distance of camera, it activates a recognition mechanism. Alternative to this solution is a software detection of an incoming vehicle, or continual processing of the sampled video signal. Software detection, or continual video processing may consume more system resources, but it does not need additional hardware equipment, like the hardware trigger.

Image processor recognizes static snapshots captured by the camera, and returns a text representation of the detected license plate. ANPR units can have own dedicated image processors (all-in-one solution), or they can send captured data to a central processing unit for further processing (generic ANPR). The image processor is running on special recognition software, which is a key part of whole ANPR system.

Because one of the fields of application is a usage on road lanes, it is necessary to use a special camera with the extremely short shutter. Otherwise, quality of captured snapshots will be degraded by an undesired motion blur effect caused by a movement of the vehicle. For example, usage of the standard camera with shutter of *1/100 sec* to capture a vehicle with speed of *80 km/h* will cause a motion skew in amount of *0.22 m*. This skew means the significant degradation of recognition abilities.

There is also a need to ensure system invariance towards the light conditions. Normal camera should not be used for capturing snapshots in darkness or night, because it operates in a visible light spectrum. Automatic number plate recognition systems are often based on cameras operating in an infrared band of the light spectrum. Usage of the infrared camera in combination with an infrared illumination is better to achieve this goal. Under the illumination, plates that are made from reflexive material are much more highlighted than rest of the image. This fact makes detection of license plates much easier.