# IMAGE CHANGE DETECTION AS A SUPPLEMENT FOR ADAPTIVE CRUISE CONTROL WITH STOP&GO FUNCTIONALITY

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Summary

The theme of the project was to develop algorithms for image sequence analysis, allowing for improved functionality of adaptive cruise control equipped with Stop & Go function. Using Doppler radar could cause that on the small distances the object that crosses the path of the vehicle may not be detected. This is particularly important because of the Stop & Go function that allows the host vehicle to stop when preceding vehicle stops, and start automatically when the preceding vehicle pulls away. In such a situation collision with an undetected object located between the vehicles can occur. The requirement was to propose such algorithms that will work in real time and ensure compatibility with the existing system architecture.

Keywords: adaptive cruise control, image sequence analysis, change detection, image processing.

WYKRYWANIE ZMIANY OBRAZU JAKO UZUPEŁNIENIE SYSTEMU TEMPOMATU ADAPTACYJNEGO Z FUNKCJĄ STOP&GO

Streszczenie

Tematem projektu było opracowanie algorytmów analizy sekwencji obrazów pozwalających na polepszenie funkcjonalności tempomatu adaptacyjnego wyposażonego w funkcję stop&go. Wykorzystanie dalekosiężnego radaru Dopplera może spowodować, że na małych odległościach nie zostanie wykryty obiekt przecinający trasę pojazdu. Ma to szczególne znaczenie ze względu na funkcję stop&go, która pozwala na zatrzymanie pojazdu, gdy pojazd poprzedzający się zatrzyma, oraz automatyczne ruszenie, gdy pojazd poprzedzający odjedzie. W takiej sytuacji może dojść do kolizji z niewykrytym obiektem znajdującym się pomiędzy pojazdami. Wymaganiem było zaproponowanie takich algorytmów, które pozwolą na pracę w czasie rzeczywistym oraz zapewnią kompatybilność z dotychchzas wykorzystywaną architekturą sprzętu.

Słowa kluczowe: tempomat adaptacyjny, analiza sekwencji obrazów, rozpoznanie zmian, przetwarzanie obrazów.

## 1. INTRODUCTION

In the modern environment one can observe growing congestion in urban areas. This happens mainly because of rapidly growing number of cars, which leads to increase in the number of accidents happening every day. To prevent such situations, number of solutions were developed and introduced in the automotive field – majority of them can be related to as the Driver Assistance Systems. One of such is Adaptive Cruise Control with Stop&Go functionality. Adaptive cruise control in relation to classical cruise control device is additionally equipped with sensor allowing the system to adapt host vehicle speed based on the condition of surrounding environment. Stop&Go feature allows the host vehicle to brake to a complete stop when the preceding vehicle slows down to a halt by using long-range narrow beam Doppler radar to detect velocity of the preceding vehicle. Additional "automatic go" function allows the host vehicle to start driving again without driver intervention once the preceding vehicle pulls away.

As mentioned above, to estimate velocity of the proceeding vehicle long-range narrow beam radar is used. Due to limitations of radar technology and their associated field of view exist possibility that pedestrian, pushchair, bicycle or other object cross the vehicle pathway whilst it is stopped and not be detected by the radar. If the preceding vehicle pulls away under such condition, automatic acceleration of the host vehicle could result in a collision with the object. To overcome this problem most commonly augmenting the main sensor with short range wide-angle radar or laser scanner was used. However, such combination can result in a system that is prohibitively too expensive.

An alternative was proposed to use video sensor instead. Use of the video image processing to detect object that may enter the host vehicle pathway when it is a stopped condition can be used and therefore provide both required support for the narrow beam long range radar and solution to associated field of view problem. Over the years cost of video sensor has dropped dramatically and thus the integration of video technology into vehicle for functions such as lane detection has become more widespread. Combined with the fact that video technology is becoming inexpensive, especially when multiple functions and algorithms can be integrated within the same camera unit, makes the use of this technology very attractive.

### 1.1. Cruise Control Systems

Cruise control systems were initially introduced to make driving experience more comfortable and pleasurable rather to make it safer. Vehicle driver was able to set desired cruising speed which will be kept by the device. However, because no additional sensors were applied this system needed continuous driver attention. Only the addition of front-end sensors allowed for more autonomous system introduction. First mass production car equipped with ACC (sometimes also referred to as ICC – Intelligent Cruise Control) was introduced by Toyota in 1998. ACC uses radar, microwave or laser technology to detect approaching vehicle and adjust the speed automatically [2]. This allows to set desired cruise speed which will be reduced if any object will appear in sensor field of view and to automatically accelerate when conditions will allow.

### 1.2. Technical constrains and requirements

For the solution for the problem of radar associated field of view image processing and analysis algorithms were proposed. The main requirement was to develop such algorithms that will provide real time environment change detection. However as such an algorithm was intended to run simultaneously with other algorithms and functions within one camera unit, constrain of platform compatibility was imposed.

To provide robust sensing covering the entire road surface for all kinds of driver assistance systems the video sensor needs to provide high temporal rate, good resolution, wide angle and high dynamic range. Therefore considerably big amount of data needs to be processed. Traditionally suitable system architecture consist of one or more Digital Signal Processing devices or custom ASIC (Application-Specific Integrated Circuit), both of this approaches states numbers of advantages and limitations. DSP is hard to program due to low-level assembly language and can be easily overloaded by the algorithm and as such prevent any further system development. ASIC circuits posses high performance, low power consumption and low unit price. However, ASIC development process is very difficult and expensive and may be reasonable only for mass production. What is more ASIC, similarly to DSP, is not convenient for algorithm and system development, as it is purpose-designed and hard to extend.

As the best solution for development processes regarding cost and performance balance use of an FPGA array was proposed. Field Programmable Gate Array allows for project specific configuration after unit production.

However FPGA provides very good performance use of this particular technology puts additional constrain on proposed algorithms. Because of small amount of FPGAs internal memory algorithms cannot use image frame buffer. That implies need for the feature based approaches development.

To summarize three main constrains were recognized:

- real time change detection;
- architecture compatibility for multi functional system;
- feature based approach to overcame limited amount of FPGAs internal memory problem.

## 2. SOLUTIONS

As mentioned above to the problem of associated field of view of radar sensor, use of wide range video sensor was proposed together with application of image sequence processing and analysis in order to detect environment change [3]. During the project two main sets of algorithms were developed, each of them oriented on solution of separate problem. First set was aimed to solve the problem of redundant data amount due to use of the wide range video sensor. Algorithms from second set were aimed at robust scene change detection.

### 2.1. Image area trimming

To ensure the possibility of using a single optical sensor, allowing it to be used up to a large number of tasks it was necessary to use wide-angle camera. However in situation described in the project, data only in considerably close distance to the proceeding vehicle is relevant. Movement or changes taking place in the extreme corners posses no significant information and can be treated as a noise, and as such needs to be filtered. In fact processing area may be limited only to the preceding vehicle and its closest vicinity. Boundaries should be stretched in order to comply with geometrical relations between host and preceding vehicle and to improve safety.

For detection of preceding vehicle position and orientation following algorithm was modeled. First step was to threshold base image and perform Hough transform to obtain set of lines based on scene edge and boundaries [4, 7]. However majority of acquired lines are not relevant to vehicle area marking and thus need to be filtered. Due to its memory limitations FPGA is unable process whole image and robustly detect near-horizontal lines. To model this feature all near to horizontal lines were filtered out.

Fig. 1. Relevant image area

Next step was based on dividing line segments into those lying on the left and right part of the scene. Basing on the regular symmetric property of vehicles further filtering was imposed by rejecting right leaning lines lying in the right image section and left leaning lines in the left image section. By this step only those line segments are present that can create vehicle contour. However still considerable amount of data can be present in the line segment set, i.e. building edges, lanterns or other cars. To dispose of those false edges line segments were paired basing on their geometrical position in the image. This was done iteratively and with subject to threshold.. The last step contained choosing the most center-scattered lines as possible vehicle boundaries. Basing on their position in the overall image decision is made:

- use whole image when lines lie too close and can be considered as false edges;
- use whole image when lines lie too far from each other and can be considered as false edges;
- use trimmed image when lines lie in the area including correct tolerance.

**2.2. Scene change detection**

Developing set of algorithm for scene change detection was the main aim of the project. Five algorithm were developed and compared:

- Direct Frame Comparison;
- Image Feature Extraction and differencing;
- Image Feature Extraction and direct matching;
- Neighboring frames feature comparison;
- Optical Flow change detection.

Frame differencing is the most popular method for image change detection [6]. This approach is based on direct subtraction of image frames to reveal their difference and its usefulness was widely investigated. Despite potential high efficiency this method cannot be used for FPGA due to the need of at least two frames buffer. This method was developed to obtain good comparison background.

Second algorithm was based on two main steps: image feature calculation and extraction followed by direct frame subtraction. Despite number of noise reduction techniques (i.e. background features averaging, comparison kernels) it was revealed that this technique is not robust and can result in irregular change detections.

Two next algorithms are based on the same general idea to detect, recognize and collect image features [9]. Because of that whole change detection algorithms are performed exclusively on the feature sets and thus are perfectly suitable for FPGA arrays. The main difference is the source of basic information for the algorithm – background image. While for the Image Feature Extraction and direct matching background image is collected at the beginning of the process, for the Neighboring Frames Feature Comparison background frames are changing iteratively over time [8]. Following image feature comparison and matching is similar for both approaches and involves cascade filtering. Firstly direct matching is performed whilst all features lying in the same image geometrical positions are filtered out. Secondly, features are compared by their position in relation to other features lying in the closest vicinity (based on the kernel), thanks to this noise due to camera lateral movements is removed. Third filtering step consist of filtering isolated features. This is done by iteratively calculating Euclidean distance between all resulting features. By doing this image clusters are recognized. Such clusters can be referred to as significant image change.

The last step is based on calculation of temporal moving average – averaged change in relevant features number over time. By calculating this, noise spikes in feature number can be filtered. Those spikes are due to irregular lightning conditions, camera movement or irrelevant and uneven environment changes.

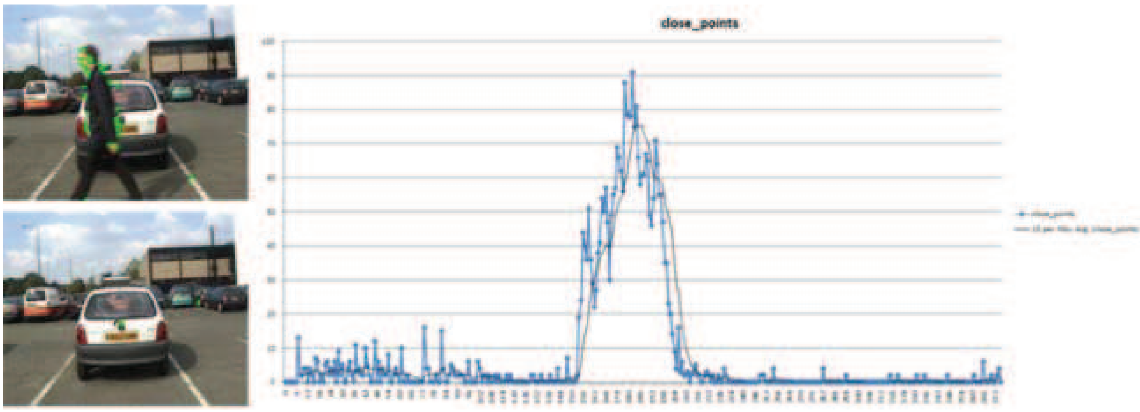


Fig. 2. Temporal features spectrum

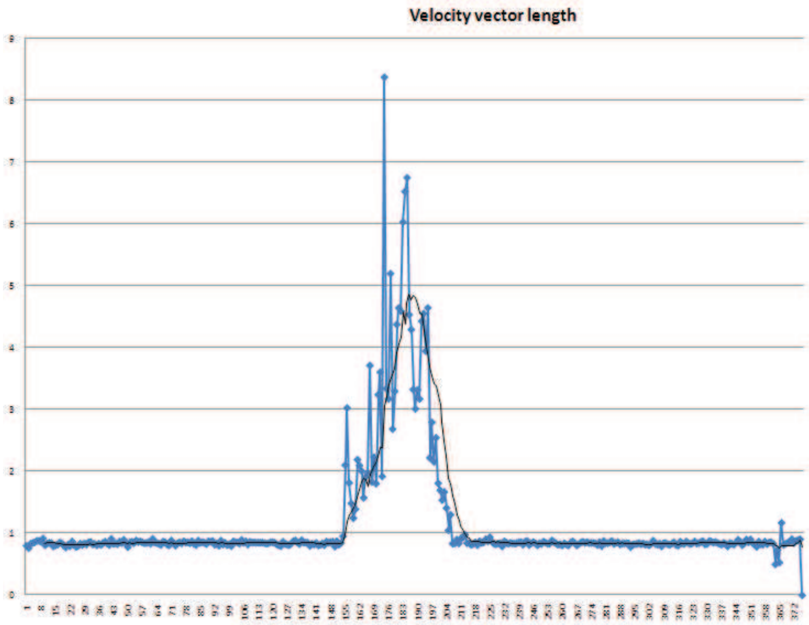


Fig. 3. Temporal optical flow velocity vector length

The last algorithm is purely based on the optical flow method [1, 5]. As an output from this function set of vectors determining corners position change is returned. Those vectors may be referred to as a corner velocity vectors. Under normal conditions vector length is very small and exists only due to the noisy lateral movement of the camera. When the change occurs vector length rises significantly.

## 3. RESULTS

It was shown that by use of the firstly captured frame, feature extraction, their filtering and matching based on the symmetry property, preceding vehicle area could be correctly estimated. One has to remember that there are two failures possibilities. First one is that too narrow area is obtained. Because of that area in which proper object is situated (or moving) will not be considered as area for which breach detection algorithms will be performed. This situation carries a possible serious health and safety issue and because of that feature span condition was applied. The second one is that significant features will not be recognized. This is trivial case as leads to full area processing and will not state safety problems. To improve area-trimming algorithm following steps are proposed:

- use of adaptive thresholds;
- filtering process verification by altering sequence steps;
- feature detector parameters tuning.

It was also shown that it is possible to obtain good results in change detection thanks to the algorithms based purely on feature comparison. All three methods (Optical Flow, Image Feature Extraction and Direct Matching, Neighboring Frames Feature Comparison) allow detecting image change, thus possible pathway breach, reliably and robustly. The noisiest output is obtained from neighboring frames feature comparison but in the same time this algorithm is the fastest proposed. Optical flow is the most complex and advanced measure not only to detect but also track occurring changes. Each velocity vector carries information about its space location and direction. Because of that not only change position may be obtained but also direction of movement of possible threat.

For the further work integration of Image Feature Extraction and Direct Matching and Neighboring Frames Feature Comparison algorithms is considered. Such an approach can utilize strengths of both approaches. Background comparison method allows to reliably detecting all changes in the scene but is sensitive to any camera movements and background displacements. Instantaneous change detection allows capturing all fast occurring changes but is not able to detect static obstacles. Combination of those approaches may create one resistant to most of the problems encountered during this project.

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