Computerized Recognition of Traffic Signs Setting Out Lane Arrangements

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Abstract: Traffic signs setting out lane arrangements provide important and useful information for drivers, even when the road signs painted on the road surface are not visible for some reason. Though automatic traffic sign recognition systems are gaining real momentum and recent high-end cars are equipped with such systems, lane info traffic signs are often neglected by these systems. It is because of the high variability of the lane arrangements and their arrow-based representations. Herein, a syntactic approach is presented to describe lane info traffic signs and to decode and recognize their message in an automatic manner. The morphological features used for the purpose are kept intentionally simple at this stage of the research.

Keywords: Traffic sign recognition; Syntactic pattern recognition; Morphological image processing

1   Introduction

1.1   Motto

"In one drop of water are found the secrets of all the endless oceans." goes the often quoted proverb by Kahlil Gibran (1883-1931). The proverb then continues with another metaphor: *"In one aspect of you are found all the aspects of existence."*

These similia may sound too *philosophical* and *poetic* to be included in a technical research paper which deals with computerized traffic sign recognition for smart car applications, in general, and which presents a syntactic [1] and morphological [3] approach for understanding, decoding the lane arrangement – of a road, or of a junction – from the image of a lane info traffic sign in particular. Such signs are shown in Figs. 1 and 4. In the former figure, a selection of signs – used in Germany, UK and Ireland – that set out the arrangements of traffic lanes for certain

road locations appears, while in the latter, a selection of those used in Hungary is reproduced.

Figure 1

Some lane info traffic signs – including a temporary lane closure sign – from various European countries

Oddly enough, the message of the aforementioned proverbs does resurface in the syntactic pattern recognition context. Using the notions appearing in the first simile, the *drop* would be the set of all those road traffic signs that provide traffic lane information for the road users, while the set of all the road traffic signs could be thought about as the *ocean*.

1.2   Pictograms and Traffic Signs

Looking at the variety of arrow shapes, the variety of curved and straight bevels used for indicating turning lanes, allowed turning and/or straight directions in Fig. 1, one feels a bit frustrated to see that there is no common European methodology, neither in respect of traffic sign shapes/designs in general, nor in respect of lane info traffic sign shapes/designs in particular. In fact, only the traffic signs specified in the Vienna Convention look *fairly similar* in the various European countries, other road traffic signs vary considerably within Europe and they vary even more around the world. Therefore, to simplify the recognition task at hand, herein we shall limit our investigations to the *Hungarian dialect* of lane info traffic signs.

Natural languages and iconic sign languages, such as the traffic signs, use automatic and more complex signs to construct their respective *sentences*. In their review of linguistic approaches to the design, the understanding and the usage pictograms [6], Tijus et al. set out and explain the linguistic construction of traffic signs.

Among other pictograms and traffic signs, they analyze the layout of the "No overtaking" traffic signs, i.e., the one that applies to all kinds of vehicles including trucks and the one that applies only to trucks. The former is constructed with the template for "No overtaking" (see Fig. 2) and a "red" car – i.e., the car being in offence – is inserted to the left[1] of the black car, i.e., the one driven lawfully. Apart from its construction and layout, Tijus et al. also derive and analyze the meaning of the signs.

The traffic sign mentioned above comprises very few constituent images (i.e., black and red car/truck shapes and red bordered white disk) compared to the more complex lane info traffic signs, such as the ones shown in Fig. 4. On the other hand, some of these constituent images are fairly intricate compared to the most frequently used basic primitives (i.e., arrows, stripes and blocks) of the lane info traffic signs.
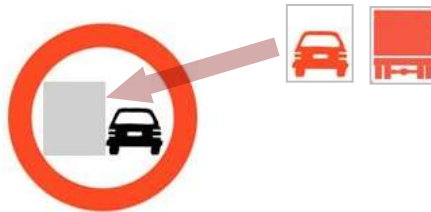

Figure 2
Template for the "No overtaking" traffic signs

For instance, in the lane info traffic sign shown in Fig. 4f, there are eight arrows with all together nine arrow heads. The lane info traffic signs are usually more geometric in their character and are more repetitive than the warning and a prohibitory traffic signs considered in [6]. These characteristics of the lane info traffic signs are not surprising, if one considers that the lane info traffic signs convey, possibly together with some other information, the arrangement and structure, i.e., the *geometry* of the road.

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[1] Note that in the UK, where drivers must keep to the right, the template changes to .

1.3   Traffic Lanes, Lane Markings and Lane Information

Traffic *lanes* are used by the road authorities and road engineers to make the traffic patterns on the roads and at junctions clear-cut and easy to grasp. The aim of this practice is to make the roads and junctions safe for all the different types of road users.

The lanes are marked on the roads and at junctions using white or yellow stripes of different styles (e.g., solid simple line, solid double line, various dashes lines depending on the road environment and road type). The *lane directions*, e.g., straight, turning, are marked with arrows painted in the middle of the lane. The lanes with their markings provide reliable spatial handholds for the drivers and for automatic lane keeping assistant systems [7] alike.

But even the iconic sign language of lane directions change over time. Recently, for example, some up-to-date *multi-lane roundabouts* were installed on the Hungarian main roads, particularly at busy junctions with a long record of road accidents. As a consequence and at the same time, new arrow shapes and configurations had to be introduced in the lane markings and lane info traffic signs. Such a busy junction and the corresponding lane marking and lane information traffic sign are shown in Fig. 3.

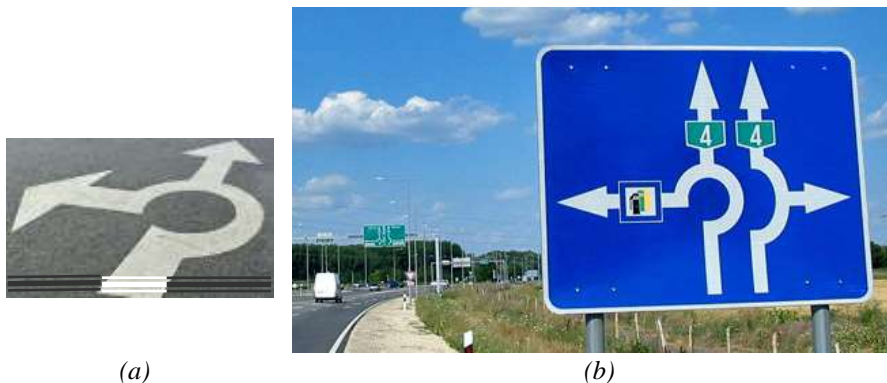*(a)*   *(b)*

Figure 3

Lanes leading into a multi-lane roundabout traffic system near Szolnok, Hungary. Lane directions indicated on the road surface and on the lane info traffic sign.

In their paper [10], Danescu and Nedevschi present a method for detection, measurement and classification of lane markings and arrows – painted on the road surface – indicating the prescribed direction of the traffic for the particular traffic lane. Their method is part of an automatic driving assistance system dedicated to intersection safety and identifies the arrows based on their dark-light-dark transitions on horizontal line regions – see Fig. 3*a* – in the perspective image taken by the on-board camera. The initial fairly crude image segmentation is then

refined using gray level segmentation based on Gaussian mixtures. A small set of shape and size features is used for the decision tree-based classification of the arrow and line shapes.

1.4   Lane Information road Traffic Signs

The lane information – provided in a pictorial manner by the traffic signs that set out the arrangements of traffic lanes for certain road locations (referred to as *lane info traffic signs* in the following) – includes the number of, the arrangement of traffic lanes, and also the changes of these (e.g., lane merges, parting of lanes, lane closures). The lane info traffic signs are simplified representations of the lane arrangements. They also warn of the traffic signs controlling the traffic over the individual lanes.

The lane info traffic signs facilitate the perception and understanding the lane arrangement, particularly when there is snow cover on the road surface (i.e., the lane markings are not visible), or the traffic is too busy and the huge vehicles block the views of the drivers. In such cases, the lane info signs provide an alternative medium for conveying the essential *lane-related* and/or *lane-specific* traffic safety information to drivers.

Lane info traffic signs may specify the types of and even the priorities between the lanes, as well as, the current and the subsequent directions of the traffic lanes. They reveal the lanes leading into the junction ahead, the layout of a multi-lane road. Furthermore, there are lane info traffic signs which warn the road users of lanes meant to be used solely by buses and taxis, and of lanes reserved for the cyclists, or, for that matter, of lanes reserved for buses, taxis and cyclists.

Various lane-specific prohibitory, order giving, and warning traffic signs may appear embedded into the lane info traffic signs. See Figs. 4b and e. Furthermore, the lane information concerning two consecutive road locations is sometimes merged into a single *compound lane info traffic sign*. It is normally done so in case of more complicated lane arrangements near bigger junctions. A concrete compound lane info traffic sign is shown in Fig. 4f. In fact, such recurrences of traffic signs – embedded into lane info road traffic signs – were the reason for us to cite the proverbs from Gibran in the motto.

(a)   *(b)*

(c)   *(d)*

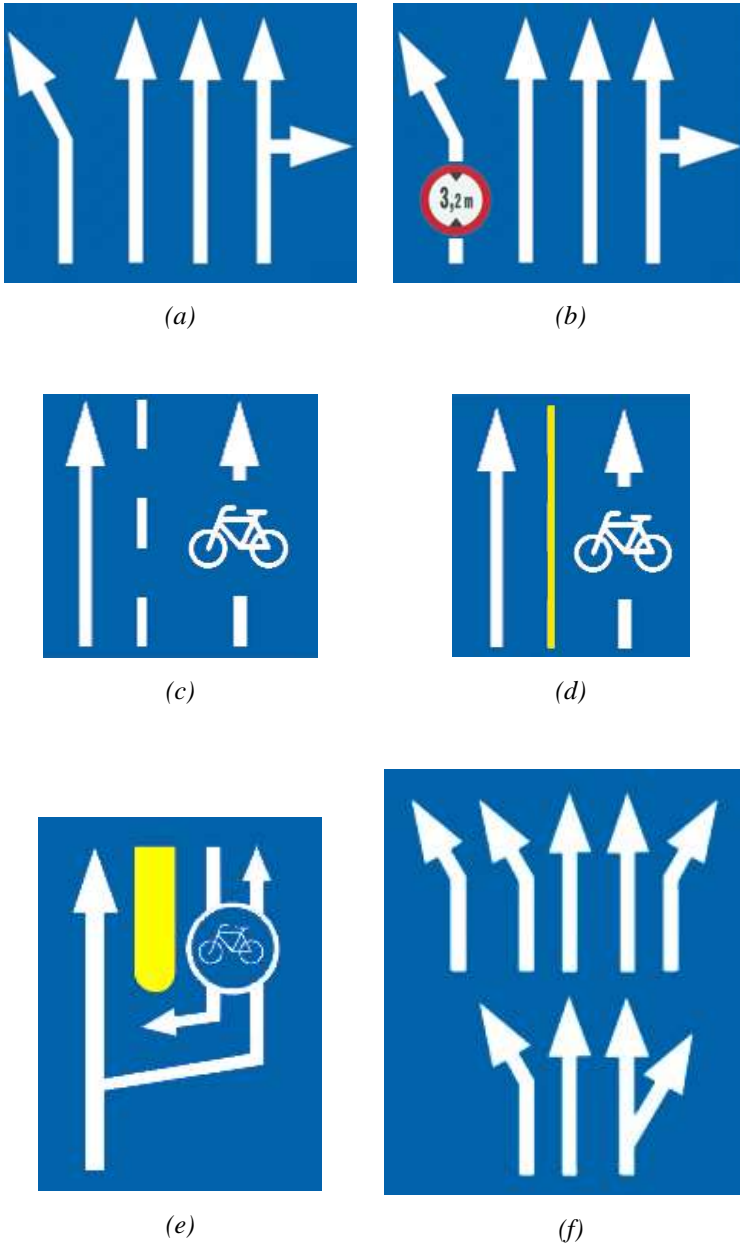*(e)*   *(f)*

Figure 4
Appropriate traffic lanes at junction ahead

The many possible lane arrangements and the numerous possibilities of lane-specific signs make the lane info traffic signs a relatively difficult target – compared to other more uniform traffic signs, e.g., speed limit traffic signs – for automatic traffic sign recognition [12]. As a consequence, though automatic traffic sign recognition systems are deployed in new cars at an increasing rate [8] and many high-end cars are equipped now with such systems, the *lane info traffic signs are often neglected* by these recognition systems because of the high variability of the lane arrangements and their corresponding arrow-based representations. It is so, despite claims that many of these recognition systems are able to recognize *"almost the complete set of traffic signs"*. For instance, a similar claim is made about a real-time traffic sign recognition system presented in [14]. The system presented there uses a template-based pattern recognition approach, but does not seem to address the recognition of lane info traffic signs.

Apart from arrows and other traffic signs, also white/yellow solid and dashed lines – e.g., marking the side of the hard shoulder, or the lane borders/endings – and yellow/gray/red blocks – e.g., indicating the side of the road, or lane closure – may appear in various national lane info traffic signs.

2 The Image Language of Lane Info Traffic Signs

2.1 A Simple Image Grammar for Generation of Lane Info Traffic Signs

The lane info traffic signs are formed of some re-occurring primitives (e.g., arrows, lines and blocks of different kinds). The placement of these primitives is not *ad hoc*, it follows certain geometric and connection rules. These primitives, connections and rules together can be seen and formulated as an *image grammar* [1]. Similarly to other formal grammars, an image grammar comprises a start symbol, a set of production rules, a set of nonterminal symbols and a set of terminal symbols. These constituents also appear in the image grammar shown in Fig. 5.

One can generate similar images, in this case, lane info traffic signs, using different image grammars. For example, one could describe the image content (i.e., the layout of the traffic sign in this case) at different levels of detail by selecting simpler or more complex primitives (e.g., pixels, lines, corners, vertices, stripes, triangles and arrows).

Grammar generating the same language can differ also in the direction of the construction. The grammar shown in Fig. 5 builds the lane structure from left to right – i.e., ⎞, ⎞⎞, ⎞⎞⎞ , … – as it can be traced in Fig. 6, but it is straightforward to

modify the grammar so that it will proceed from right to left, i.e., setting the rightmost lane first $\int$, then the one next to it: $\iint$, and so on $\|\iint$.

A simplified version of the image grammar for lane info traffic signs – called *SimpleLaneGrammar* – is presented in Fig. 5. The grammar is simplified in the sense that it generates only simple (i.e., not compound) lane info traffic signs with uniform lanes, with neither embedded traffic signs, nor separating lines/blocks.

A further restriction is that the lanes may only turn left, go straight, turn right and any (safe/legal) combination of these directions are allowed, but neither U-turn/roundabout lanes, nor lanes turning to any other directions (e.g., lane turning slightly to the right) are modelled.
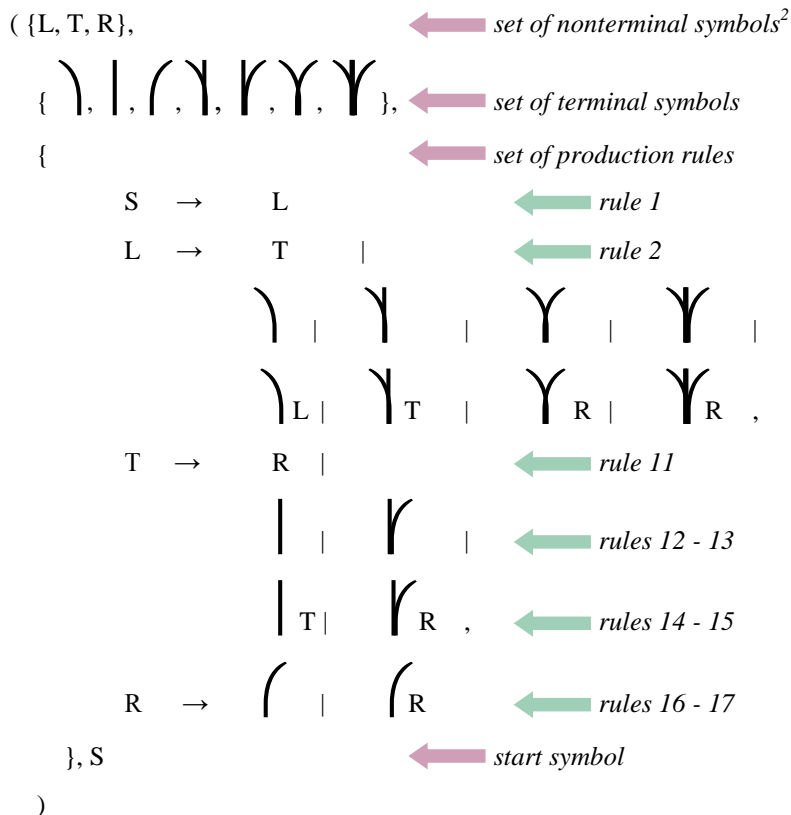

Figure 5

Formal image grammar for simple lane info traffic signs

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[2] The nonterminal symbols were selected from the English words Left, sTraight and Right.

Note that in Fig. 5, the arrow-heads are not marked (i.e., the terminal symbols, such as $\rangle$, $\int$ do not have arrow-heads).

$$S \Rightarrow_1 \quad L \Rightarrow_7 \quad \rangle L \Rightarrow_7 \quad \rangle\rangle L \Rightarrow_8 \quad \rangle\rangle\rangle Y T \Rightarrow_{14} \quad \rangle\rangle\rangle Y\mid T \Rightarrow_{14}$$

$$\rangle\rangle\rangle Y\mid\mid T \Rightarrow_{15} \quad \rangle\rangle\rangle Y\mid\mid\mid R \Rightarrow_{16} \quad \rangle\rangle\rangle Y\mid\mid\mid \int$$
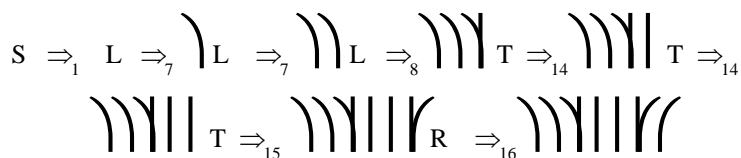
Figure 6

Derivation of lane info traffic sign for a particular junction using the indicated production rules from the SimpleLaneGrammar

In Fig. 6, the lane arrangement of a seven-lane road leading into a major junction is derived using the numbered rules of the *SimpleLaneGrammar*. The two leftmost lanes can be used solely for turning left, the next lane can be used both for turning left and for proceeding straight, two lanes further right can be used solely for proceeding straight, next lane can be used both for proceeding straight and for turning right and the rightmost can be used solely for turning right.

2.2   Parsing Lane Info Traffic Signs

The image grammars can be used not only in the generation images, or in the concrete case, in the generation of lane info traffic signs, but also in their recognition, (i.e., in decoding their structure and understanding the traffic environment and the lane structure specified by them). In the rest of the paper, we will deal with this aspect.

In Section 2.3, we present to a fairly simple approach that can recognize lane info traffic signs with no embedded traffic signs, with uniform lanes (i.e., no bus lanes, no lanes for cyclists, no barriers, and no dashed lines) and with lanes turning left, going straight and turning right, and any common combination of these. For this approach, the bounding boxes will be used as primitives. Note that the "common combinations" – i.e., the allowed intra-lane and inter-lane direction combinations – can be expressed using the production rules.

In Section 2.4, we present a stripes-and-arrow-heads based approach, which can cope with more complex layouts. For both of these approaches, we assume ideal imaging circumstances, noiseless and undistorted images.

2.3 Using the Bounding Boxes as Image Primitives

In Section 2.1, a simplified lane grammar *SimpleLaneGrammar* was introduced and it was used to construct of a simple lane info traffic sign as an example. In the present section, the compound lane info traffic sign shown in Fig. 5f will be used as a running example. For the reader's convenience, the mentioned compound lane info traffic sign is repeated in a somewhat smaller form as part of Fig. 7.

Though *SimpleLaneGrammar* cannot generate the whole compound lane info traffic sign, it can generate the upper and the lower halves of the traffic sign. The derivations of these halves are given in the mentioned figure.

Using a small trick, namely taking good care of the halves' relative positions with respect to each other, a *SimpleLane* version of the lane info traffic sign has been constructed. This trick again could be formulated as an image grammar. To emphasize the similarity between the original compound lane info traffic sign and its *SimpleLane* version, the latter is shown – using white for the terminal symbols and blue for the background – under the former one on the right in the figure.

The most important difference between this *TrickyGrammar* and the *SimpleLane-Grammar* is that the former places the terminal symbols not only from left to right, but would also proceed, say, from the top to the bottom. Also, the background spaces need to be modelled by the former in some fashion.
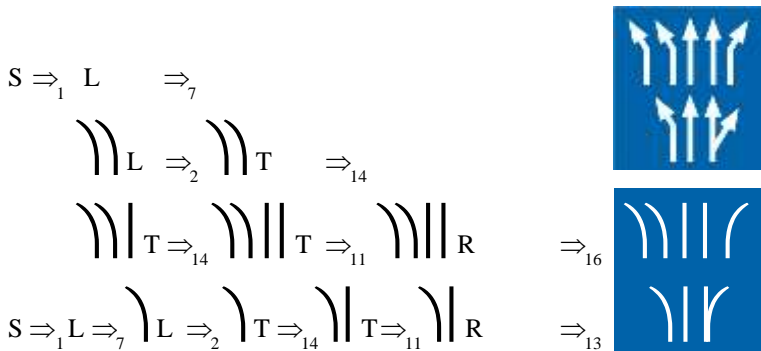

Figure 7

Derivation of upper and lower halves of compound lane info traffic sign shown above

If we now consider the task of automatic understanding/decoding the lane info traffic signs, furthermore, if we rely on the very same simplifications as had been utilized in conjunction with the simplified image grammar for lane info traffic signs, then the bounding boxes could be used for characterizing the arrow-shapes of the lane info traffic sign.

The main steps of the processing that is based on the bounding boxes and is carried out in respect of the compound lane info traffic sign shown in Fig. 7 are demonstrated in Figs. 8a - f.

First, the vertical division of the traffic sign is checked. It can be detected, for example, via computing the horizontal projection of the white pixels and looking for sections with no white pixels present at all, or via computing the morphological opening of the negated image with a long horizontal line used as structuring element. The resulting image of the latter approach is shown in Fig. 8a. In the figure, the various image segments are shown color coded: the arrows are yellow, the separating gap is brown, the "empty" borders at the top and at the bottom are dark gray and the background is middle gray. Secondly, the lane info traffic sign is partitioned horizontally. The result of this step is shown in Fig. 8b.

In the figure, the arrows themselves are not shown; only the 2D block-and-gap structure of the lane info traffic sign is displayed in shades of gray. Thirdly, the bounding boxes of the arrows are computed. The frames of the boxes are marked with cyan lines in Fig. 8c.

In Fig. 8d, the bounding boxes of the arrows (shown as yellow rectangles) are overlaid on the 2D blocks (shown in light gray) of the lane info traffic sign. It is worthwhile to discuss the various inclusions, or for the matter, the lack of these, as well as, the relative sizes of the blocks and boxes appearing in the figure.

The central narrow blocks are now fully yellow. These correspond to straight arrows (i.e., straight proceeding lanes with no turning allowed). In the top right light gray block, there are two bounding boxes: one narrower and one wider. However, there is no bounding box (i.e., no arrow) present in the bottom left block.

In Fig. 8e, the bounding boxes are colored according to their relative width. The narrowest rectangles – marked yellow – indicate straight arrow (without turning); the darker yellow rectangles correspond to bent arrows (i.e., lanes used solely for turning left/right). Finally, the orange rectangle corresponds to a double arrow (i.e., a lane that can be used both for proceeding straight and turning left/right).

Rectangle corresponding to a triple arrow – allowing each of the following movements: turning left, proceeding straight and turning right – does not appear in the concrete image; nor does the double arrow that allows both left and right turns, but not straight movement. Such rectangles would be even wider and could be marked with another color.

Having found and identified two yellow boxes placed over one another in Fig. 8e, we are now in the position to work out the turning directions of the lanes, the types of the arrows appearing in the lane info traffic sign and the lanes leading to – or feeding into – other lanes (e.g., the "lower" rightmost lane leads to the two "upper" lanes on the right according to Fig. 4f) based solely on the sizes and positions of the blocks and boxes.

The boxes shown in light red signify left turns; yellow is used for marking the straight movement, while green marks the right turn in Fig. 8f. The box colored yellow changing to green marks a lane that can be used both for proceeding straight and turning right.

Looking at the *vertical arrangement* of these colored boxes, it is easy to work out that the lane corresponding to the yellow-green rectangle feeds into lanes above it. While the lane corresponding to the top left (light red) box must be fed by the lane corresponding to the (light red) box, which is under its (light red) neighbor.

Note that in the above example, we could rely on the reference position set by the two yellow boxes appearing over one another (i.e., the central straight arrows signifying a straight lane feeding into another straight lane closer to the junction) to unambiguously determine the turning directions.

(a)

(b)

(c)

(d)

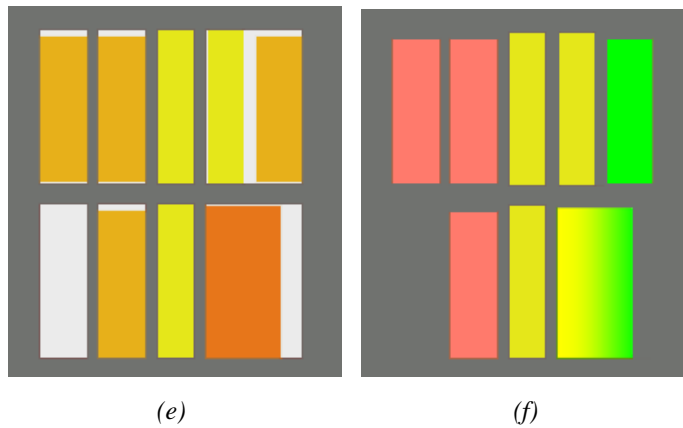*(e)*   *(f)*
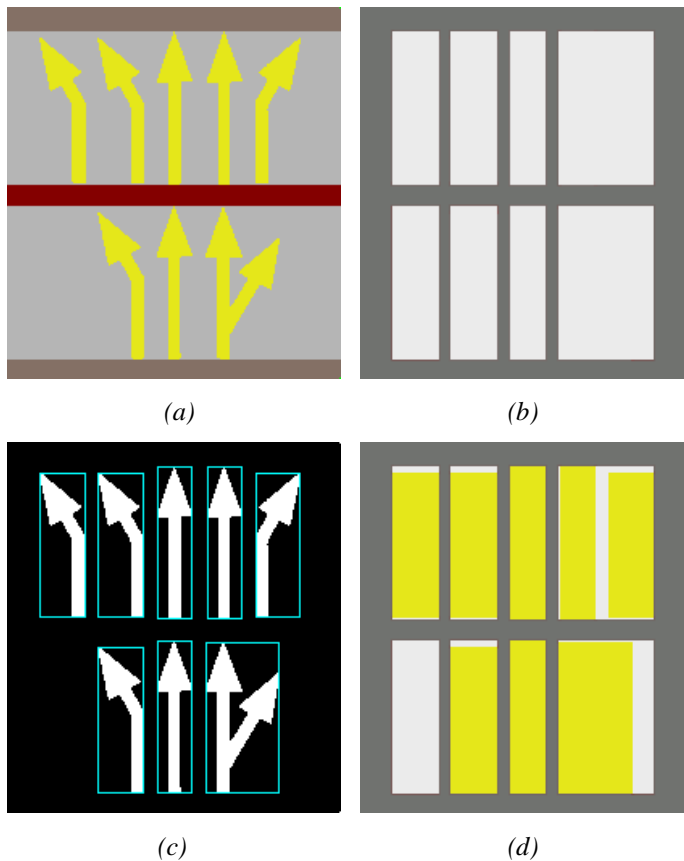
Figure 8

Derivation of upper and lower halves of compound lane info traffic sign shown above

In a lane arrangement without a lane used solely for straight movement, it might not be possible based on the fairly limited information used in the bounding box approach. In such cases, a more elaborate analysis of the arrows must be used. Such an approach is presented in the next section.

2.4   Using Stripes and Arrow-Heads as Image Primitives

As we have seen in the previous section, using the bounding boxes of the arrows and the block structure of the traffic sign only, is not sufficient for the unambiguous decoding of lane info traffic signs.

(a)   *(b)*
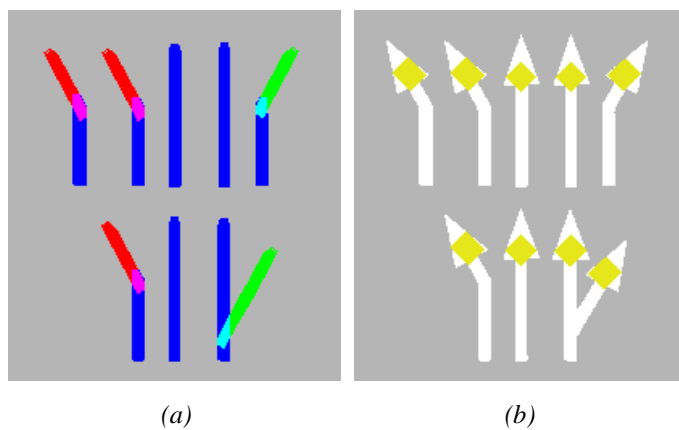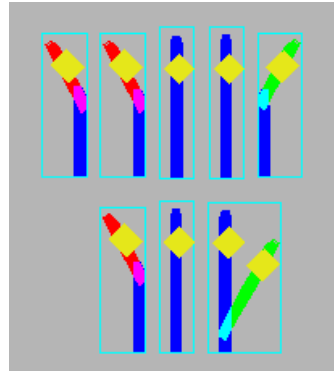
(c)

Figure 9

Main steps of processing in case of compound traffic sign

In these more complicated cases, but still relying on the restrictions stated in Section 2.1, one can locate stripes of different directions in the image [5] – in addition to the bounding box and block structure analysis – and look for and analyse overlapping areas of stripes, or for that matter the lack of those, in order to establish the arrow types of the detected blobs. Twelve directions should be enough for most cases. In Fig. 9a, the overlapping areas appear in magenta and cyan. In Fig. 9b, the arrow-heads are detected using multiple morphological openings. For this purpose, diamond-, or disk-shaped structuring elements of different sizes (i.e., granulometries) can be applied. The purpose of using granulometries here is to ensure the robust and reliable detection of the arrow-heads [14].

In Fig. 9c, the identified bounding boxes, arrow-heads and stripes are shown in a single image. Relying on these image primitives – in case of the specified subset of lane info traffic signs – one can achieve an unambiguous classification of the arrows and in turn work out the lane arrangement on the road or at the junction nearby.

Conclusions and Future Work

Traffic signs setting out lane arrangements provide important and useful information for drivers, even when the road signs and markings painted on the road surface are not visible for some reason (e.g., because of vehicles waiting/ moving over them, or being covered by snow, leaves, etc.).

Internationally automatic traffic sign recognition systems are gaining momentum and recent high-end cars, often referred to as smart cars, are now equipped with such systems. Still, lane info traffic signs are often neglected by these systems (e.g., a traffic sign recognition system may be able to locate lane info traffic signs, but their precise message is not decoded fully) due to the high variability of the

lane arrangements – and consequently that of their arrow-based representations – and of the lane-specific traffic signs embedded in the lane info traffic signs.

Herein, a syntactic approach was presented to describe a certain subset of lane info traffic signs and to decode their message in an automatic manner. The morphological features used for this purpose are kept intentionally simple at this stage of the research: a bounding box-based approach was presented and tested for a fairly complex lane info traffic sign in Section 2.3, while an approach relying on stripes-and-arrow-heads was presented and validated using the same test case in Section 2.3.

The palette of morphological features used in the lane info traffic sign recognition, however, could be extended and a syntactic recognition approach based on – or combined with – some more informative shape features and primitives, such as *affine moment invariants*, could be developed in a later phase.

The affine moment invariants were proposed for various image processing tasks in [2] and [9]. These invariants proved useful in image description and registration tasks involving images showing branching objects, e.g., in respect of the retinal vascular network appearing in ophthalmological images [4], and therefore, are seen promising in the present application area featuring branching arrows of wide variety and shape. We plan solve the sensing, noise and distortion issues. As a coincidence, the approaches that are based on affine moment invariants also seem to be suitable for eliminating the practical image distortions of traffic signs. We note here, that there are also *invariants for blurred images* [2]; and motion blur is obviously a very relevant degradation, in the case of images taken by cameras mounted on cars.

More complicated lane arrangements and localization of embedded traffic signs will be considered in future work.

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