INNOWACYJNA GOSPODARKA NARODOWA STRATEGIA SPÓJNOŚCI
INSTYTUT TECHNOLOGII EKSPLOATACJI PAŃSTWOWY INSTYTUT BADAWCZY RADOM
UNIA EUROPEJSKA EUROPEJSKI FUNDUSZ ROZWOJU REGIONALNEGO

Project co-financed by the European Union from the European Regional Development Fund

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HYBRID VISION METHOD FOR VEHICLE UNDERCARRIAGE DIAGNOSTICS

Key words

Hybrid vision method, multimodal imaging, vehicle diagnostics.

Abstract

Diagnostics of a vehicle's chassis allows the evaluation of the technical state of components that significantly affect safety. The advance of measurement techniques allows for the development of special diagnostic lines in the form of complex devices equipped with computerized inspection systems used during periodic vehicle diagnostics. Means of transport, which belong to the high-risk group of fault occurrence, or vehicles used for public transport, need frequent and rapid inspection of their condition for safety reasons. Vision systems enable one to conduct automated inspection of the vehicle's chassis without the need for stopping during the measurement process. Such solutions are used in security systems, which are designed to detect missing or foreign elements that can be potentially hazardous (e.g. explosive materials) [1]. In most cases, systems with standard visible light cameras are used. There are known examples of the usage of infrared cameras during the automatic inspection of the technical condition of the brakes, bearings, and tires in trucks [2]. Hybrid vision methods combining the advantages of both measurement techniques are also applied in railroad

chassis inspection to assess the condition of the braking system, bearings, electrical systems, the detection of failures, as well as the identification of damaged or missing parts [3].

The article describes a hybrid vision inspection method for vehicle chassis that uses a measuring head equipped with two cameras: one to observe in the visible (VIS) and another to observe in the infrared (IR) bandwidths. Exemplary results of such tests performed on large-size vehicles used for public transport are presented. Both the advantages and limitations of the proposed method are given.

Introduction

This article describes the tests performed in order to develop a diagnostic method for vehicle chassis, based on a hybrid machine vision system. The majority of visual inspection systems for undercarriages currently available utilize a single observation channel composed of a standard visible light camera. Their main application is in automatic safety systems used for the detection of explosive materials, firearms, contraband, narcotics, and other foreign elements hidden inside the chassis (Figure 1). Such solutions are based on pattern finding algorithms, which compare the registered image of the undercarriage with a fingerprint, stored inside a database, created using images and their analysis. Chassis scanners are often assisted by additional cameras for automatic licence plate recognition [4].

Fig. 1. Example image of a vehicle chassis registered by a safety system [4]

The second group of undercarriage inspection systems uses infrared cameras in order to detect temperature anomalies on thermally loaded vehicle elements. Using the technique, one can inspect and diagnose the state of brakes, bearings, tires, etc. These elements have a massive impact on driving safety. In order to lower the number of accidents involving commercial trucks, an automated inspection system based on a thermal vision camera was developed. It was integrated with a weight control station by locating the camera inside a protective case. This system allows the scanning of vehicles without the need for stopping them. Thermograms are analysed by a computer at the moment when the inspected vehicle enters the diagnostic area. The results of the inspection are then presented to the station staff. If any dangerous situation, hazardous for safety is present, alarm states are visualised. This solution significantly shortens the inspection time, because manual checks of the temperature of brakes and other thermally loaded elements are omitted. Thermograms allow a precise and unequivocal inspection of the difference in temperature of elements of the chassis located on two different sides of the vehicle. For example, faulty brakes typically have a lower temperature then elements working correctly (Figure 2).

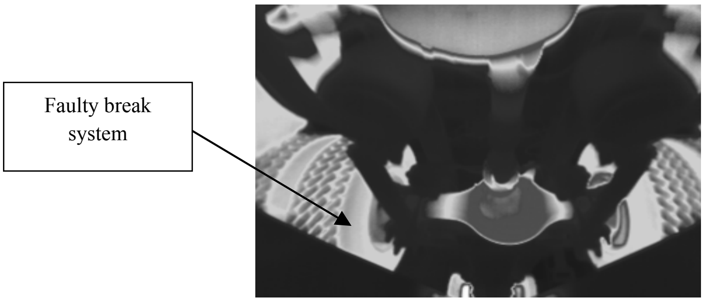

Fig. 2. Thermogram of a chassis with a faulty brake system [2]

1. Hybrid vision method

The concept of a hybrid vision method consists in the use of two cameras allowing simultaneous inspection of the object in the visible band (VIS) and infrared band (IR) (Figure 3). In order to minimize errors of perspective, the cameras should be placed in close proximity to each other and angularly positioned so that the optical axes of the two video tracts intersect on the surface of the test object. Camera lenses should be chosen in such a way that the areas of observation in both spectral ranges were similar.

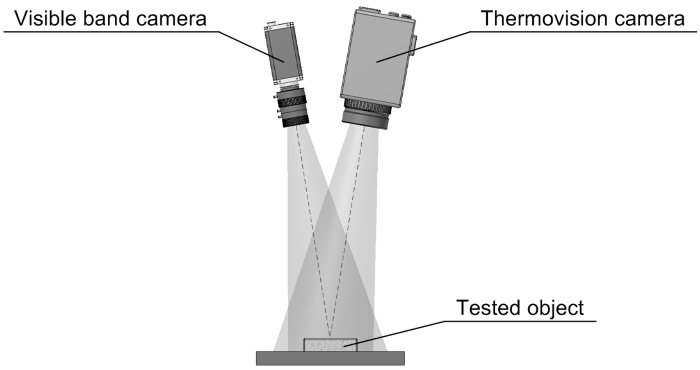

Fig. 3. The concept of hybrid vision method

The use of a hybrid vision method for the diagnostics of vehicle's undercarriages has many advantages. Images of the visible waveband are usually sharper, clearer, and have better spatial resolution than images taken in infrared. Reflected visible radiation can cause clear contrasts with sharp edges and intensity differences. Variations of the temperature distribution captured on the infrared images are usually displayed using false colours [5], which sometimes causes erroneous interpretation of the results. A similar situation can take place when observing objects consisting of multiple materials with various emissivity values. The solution is to present the infrared region of interest in a visible light image using image fusion [6]. The degree of the diffusion of the images may be freely changed from a complete picture of the infrared to the visible. The fused image is formed to improve image content and to make it easier for the user to detect, recognize, and identify targets [7]. Image fusion can be performed roughly at four different stages: signal level, pixel level, feature level, and decision level. Figure 4 illustrates the concept of the four different fusion levels.

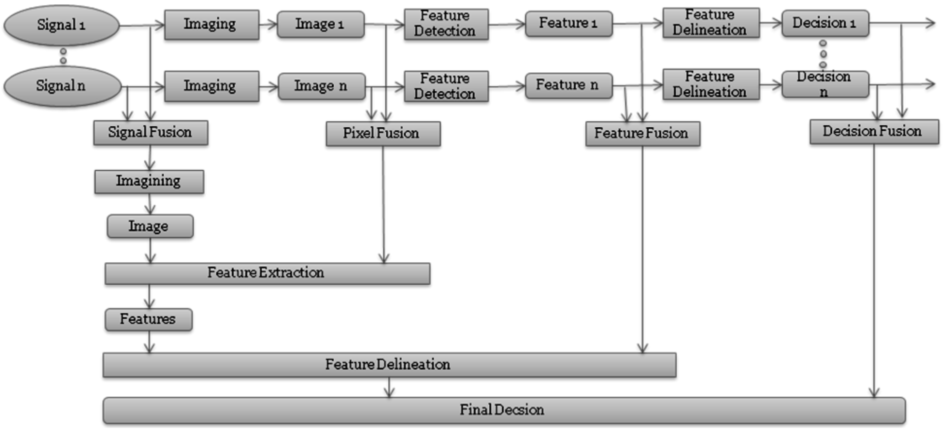

Fig. 4. A general overview of image fusion techniques [8]

In signal-based fusion, signals from different sensors are combined to create a new signal with a better signal to noise ratio than the original signals. Pixel level fusion is the combination of the raw data from multiple source images into a single image. Feature level fusion requires the extraction of different features from the source data before features are merged together. Decision level fusion combines the results from multiple algorithms to yield a final fused decision. In the presented system, we focus on the pixel level fusion process, where a composite image is synthesized from two sensor sources that significantly differ in field of view, resolution, and lens distortions. To align the input images properly with each other, image registration is required [9]. After that, the machine vision algorithms for image processing and analysis can be applied.

2. Experimental studies

In order to fully verify the proposed inspection method, it was decided to perform field tests on large vehicles. Because of the importance of their reliability and good performance for public safety, large public transport buses were evaluated. The selected buses were a 1997 Neoplan N4016 and a 2000 Solaris Urbino 12, both of which are double-axle city buses commonly used by different companies. In order to make the conditions more similar to typical ones, tests were performed during a routine inspection of the vehicles after they finish their daily runs. The inspection process was performed inside a specialised garage under the supervision of mechanics.

Figure 5 presents the placement of the proposed inspection system inside a car inspection pit. This localisation allows for easy access to the chassis and gives the mechanics the ability to perform other maintenance tasks at the same time.

Fig. 5. Inspection system placement

The measuring head, which contains two cameras, was fixed on a tripod for more precise calibration and localisation. This setup was accompanied by a halogen light source to improve the illumination conditions. Not shown on the image are a portable computer, which was used for data acquisition and observation, and a signal generator used as a simultaneous trigger for the visible light and infrared cameras.

2.1. Inspection system set-up

Because of the finite space available and the non-laboratory work environment, a hybrid measuring head was used instead of two separate cameras. The metal case containing the vision systems serves as both a protective measure against foreign objects and dirt, as well as a shield against higher temperatures. As seen on Figure 6, the case has two walls in order to isolate the camera chamber from the external factors. Additionally, an externally supplied compressed air ventilation system is also possible, although it was not used in this case. The front cover of the measuring head can be removed for camera calibration and also during inspection, if the work environment is clean enough and higher image quality is needed. The measurement head is mounted onto a tripod equipped with a Manfrotto photographic head used for 3 dimensional positioning.

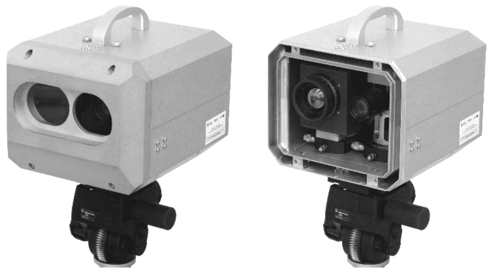

Fig. 6. Overview of the measuring head with and without the front cover

Inside the hybrid measuring head, two cameras are encapsulated: an InfraTec thermal camera and a Basler CCD visible light camera. Both cameras are mounted on rotary tables for quick and precise calibration, depending on the distance to the object. The infrared camera measures the heat radiated by objects to determine the surface temperature distribution. It can be used for locating local differences in temperature or monitoring object temperature. The visible light camera can serve as a detector of surface defects and also as an aid in localisation and object identification. Their most important parameters are described in Table 1.

Table 1. Basic parameters of the thermal and visible light cameras [10]

	Thermal camera	Visible light camera
Parameters:	Resolution: 640×480 px Sensitivity: 40 mK @ 30°C Spectral range: 7.5–14 µm, Measuring range: -40–1200°C	Resolution 1600×1200 px Sensor type: monochromatic CCD Lens type: C-mount

The placement of the measurement head inside the vehicle inspection pit forces the usage of an additional light source. During the inspection process, the vehicle chassis blocks most of the light coming from sources outside of the pit, which makes any observations done with the visible light camera unreadable. In order to increase the quality of the images, an additional light source was placed next to the measurement module. Out of commercially available light sources, a DedoCOOL halogen source manufactured by Dedo Weigert Film GmbH was chosen for the proposed system.

2.2. Results analysis

In order to acquire high quality data, the inspection process for a single bus was divided into four parts depending on the observed region. Two observations of the middle part of the bus chassis were performed and an additional two were made of the wheels and braking system. In this way, four different high quality image streams were obtained. In order to achieve different observations, because of the width of the pit, which affected the cameras region of observation, both the measurement head and the vehicle inspected had to be moved between inspections. In case of the bus, this means approaching the inspection region from different angles and in a different relation between the bus and the pit.

The vehicle inspected first was the Neoplan N4016 bus, which was the older model of the two. Because of the number of images acquired (more than 5 000 images for each bus) only a selected few frames are described in greater detail the following paragraphs.

Because of the different materials present in the vehicle undercarriage construction, it was impossible to perform accurate temperature measurements. To further complicate the studies, oxidation may cause different results in the same material due to changes in emissivity. Because of those factors, temperature values were omitted in the following paragraphs and only comparisons between different parts were provided.

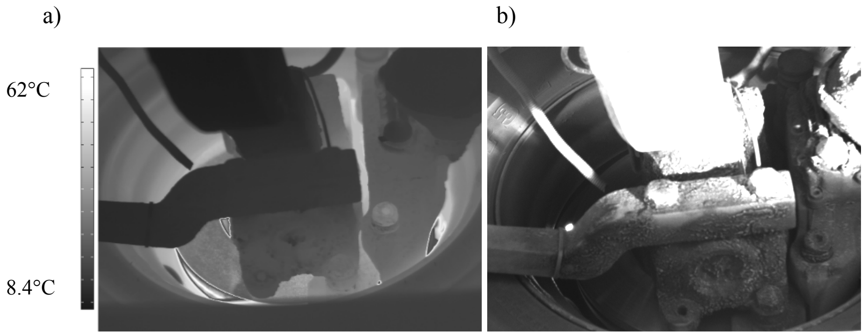

Fig. 7. Neoplan 4016 front wheel with braking system: a) Infrared image b) Visible light image

Figure 7 presents images of the Neoplan front left wheel acquired by the measuring head. Figure 7a displays the thermal image of the wheel, suspension, and brakes. The corresponding image acquired by the visible light camera is shown in Figure 7b. Wheel inspection focused on locating both cold and hot areas, which may imply defective operation of the suspension and brake system [11]. The maximum temperature of the brake disc was present on the outer rim. The temperature of other elements was significantly lower. Data gathered from other wheels, both from the Neoplan and Solaris buses, gave similar results. This small variation of results from different wheels implies that the brakes on this bus should be working properly [12, 13]. The results of the wheel inspection are within the temperature boundaries proposed in [12]. This further indicates the proper functioning of the brake system. Nevertheless, this method cannot be a substitute for the work of a trained inspector and should only be used as an aid in detecting faults.

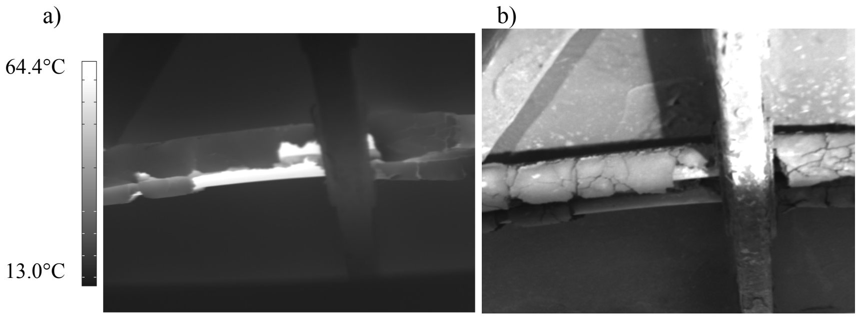

Fig. 8. Vehicle undercarriage with visible insulation damage: a) Infrared image, b) Visible light image

During the inspection process, a common occurrence was visible wear to cable and pipe insulation, present on both vehicles. Figure 8 shows an example of such damage on the Neoplan bus both in the infrared (Fig. 8.a) and visible light (Fig. 8.b) spectrum. In places where the insulation is damaged, the temperature increased substantially while the temperature of the isolated part was twice as low. Damage to insulation creates a risk of rapid deterioration of the cables due to both erosion and corrosion. Thermal imaging can be used as an effective method for the early identification of such hazards.

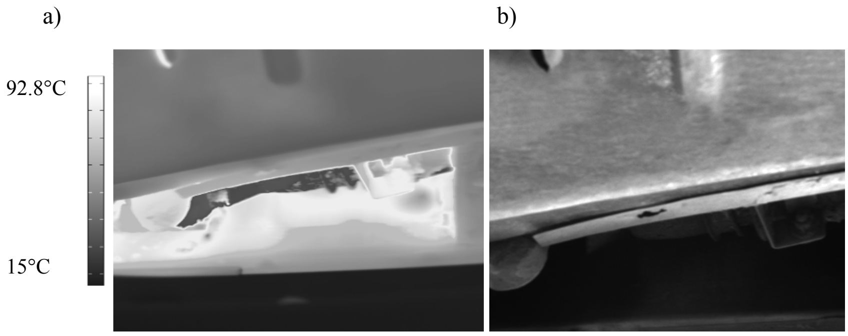

Fig. 9. Exhaust of the Solaris Urbino 12 bus: a) Infrared image, b) Visible light image

The highest temperature observed during the chassis inspection process was at the exhaust. The thermogram and image from the visible light camera are presented on Figure 9. Those images (Figs. 9a and 9b) can serve as an example for using thermal imaging as a complementary method for visible light systems. Little information about the exhaust can be read from Figure 9b. Because of the position of the chassis elements the view of the exhaust is heavily obscured and dark. However, based on data acquired by the infrared camera, one can evaluate the current temperature of the exhaust and its general shape and localisation. A similar approach of using the infrared camera for localisation of occluded objects, concentrating on terrorist threat detection, is described in [14].

It is worth pointing out that all of the analysed images were captured in good weather conditions without effects of rain or snow. Image alternations occurring during rain can affect the reflectivity of observed objects in the visible light camera and emissivity variations in the infrared waveband. Concerning the effect of snow on inspection, the proposed vision method is practically limited to the areas that are uncovered and remain warm, in which case the infrared camera can record the component's actual temperature. The described limitations also relate to classical methods, where the snow is packed so hard that it is impossible to investigate certain area by a human inspector [3].

3. Summary

The improved hybrid vision method combining an infrared and visible image analysis for vehicle undercarriage diagnostics was demonstrated. The advantages of using machine vision methods for diagnostics are, among other things, non-contact measurements, a non-destructive nature, and increased speed and repeatability of performed inspections. Additional advantages are obtained by a combination of an image recording of two or more spectral bands. The infrared vision inspection camera can be applied for automated inspection of the vehicle chassis without the need for stopping during the measurement. Furthermore, information captured by the vision camera is used to detect missing or foreign elements that can be potentially hazardous and to improve recognition and speed up the location and identification of the controlled objects or to facilitate interpretation of results. The main difficulty of applying the proposed method is the development of an optical system with a field of view large enough to cover the entire chassis of the vehicle. Using wide-angle lenses causes problems in emerging large optical distortions. Currently used thermal imaging array cameras are characterized by low resolution that can be another limitation. The solution to this problem could be the use of multi-camera setup or a specially developed high-resolution thermal linescan camera. The next step is to design and build a special enclosure that can be mounted to the diagnostic lines or installed directly in the ground [1]. Beyond the discussed aspects of the hardware structure of the system, in order to guarantee the reliability of the proposed method, future work is needed to develop efficient algorithms for image processing and analysis. The final stage of the project will be developing a decision-making module. It is planned to conduct a long process of training of the decision module based on the example inputs and their desired outputs, given by a qualified diagnostic inspector.

Acknowledgements

Scientific work executed within the Strategic Programme "Innovative Systems of Technical Support for Sustainable Development of Economy" within Innovative Economy Operational Programme.

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Metoda hybrydowej inspekcji wizyjnej podwozi pojazdów

Słowa kluczowe

Hybrydowa metoda wizyjna, obrazowanie multimodalne, diagnostyka pojazdów.

Streszczenie

Diagnostyka podwozi pojazdów umożliwia ocenę stanu technicznego podzespołów istotnie wpływających na bezpieczeństwo jazdy. Rozwój technik pomiarowych pozwolił na opracowanie specjalnych linii diagnostycznych w postaci kompleksowych urządzeń wyposażonych w skomputeryzowane systemy kontroli, które wykorzystywane są podczas okresowych kontroli pojazdów. W przypadku środków transportu, które należą do grupy wysokiego ryzyka wystąpienia usterki lub pojazdów służących do publicznego transportu zbiorowego, ze względów bezpieczeństwa istnieje potrzeba wykonywania częstej i szybkiej kontroli ich stanu technicznego. Systemy wizyjne umożliwiają przeprowadzenie automatycznej inspekcji podwozia samochodu bez konieczności jego zatrzymania podczas pomiaru. Rozwiązania takie znajdują zastosowanie w systemach bezpieczeństwa, które mają na celu wykrywanie brakujących lub obcych elementów, które mogą być potencjalnie niebezpieczne (np. ładunki wybuchowe) [1]. W większości przypadków wykorzystywane są systemy wyposażone w standardowe kamery pasma widzialnego. Znane są jednak zastosowania kamer termowizyjnych do automatycznej kontroli stanu technicznego hamulców, łożysk i opon w pojazdach ciężarowych [2]. Hybrydowe metody wizyjne łączące zalety obydwu technik pomiarowych znajdują zastosowanie również w inspekcji podwozi taboru kolejowego w celu oceny stanu układu hamulcowego, łożysk i wykrywania awarii systemów elektrycznych, a także uszkodzonych lub brakujących części [3].

W artykule opisano hybrydową metodę inspekcji wizyjnej podwozi pojazdów, która wykorzystuje głowicę pomiarową wyposażoną w kamerę do obserwacji w paśmie widzialnym – VIS (ang. *visible*) oraz podczerwieni – IR (ang. *infrared*). Zaprezentowano przykładowe wyniki badań pojazdów wielkogabarytowych wykorzystywanych do transportu publicznego. Omówione zostały zalety i ograniczenia proponowanej metody.