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Optical measurement method for high-speed quality control of viscous materials based on fluorescence

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ABSTRACT

This study presents an innovative approach of high-speed measurement for online quality control of viscous materials in a manufacturing process. The measurement method is based on fluorescence imaging and works on a non-contact basis. The measurement system captures three similar fluorescence images of a moving viscous object in different optical paths. The maximum speed of the objects being evaluated is 5 m/s. The main areas of application of this system are the detection of mixing ratios and the identification of impurities in the fluorescing viscous materials. Using the presented measurement setup, it is possible to detect very small variances in particular and unwanted components in viscous materials.

1. Introduction

Today, web inspection is applied in various ways for quality control in manufacturing processes [1]. Such systems have been used for industrial texture characterization [2,3] as well as wood [4,5], metal [6], and glass [7] processing. Currently, texture characterization in industry has the highest demand for further developments of new web inspection setups [8]. In this industry clothes, carpets, or leather materials are examined for defects or poor quality [9,10]. With the continuous development of optical and electronic components, the system quality has been increasing steadily. At present, it is possible to detect the smallest variances in materials and defects in the micrometer range during the manufacturing process at a speed of up to several meters per second. The systems work in real-time and offer the opportunity for prompt intervention. These properties make the method interesting for new applications. One such application is the quality control of viscous materials during the manufacturing process.

Viscous materials have been established in many fields, e.g., cosmetics, food, and machinery industries. This study focuses on viscous materials in the machinery industry. Currently, there are two established standard methods for quality control in manufacturing processes – those that use contact measurement and those that use contactless measurement.

Quality control processes based on contact measurement setups are very complex and require high maintenance. One approach is acoustic analysis of viscous materials [11,12]. A sample of the viscous material is taken from the manufacturing process, and a ball bearing is filled with the viscous material and fixed at a test station. During constant movement of the ball bearing, the acoustic signal of the viscous material is recorded [13]. Another approach for the contact measurement setup is the use of a near-infrared sensor [14]. Disadvantages of contact setups include the immense effort involved and the small sample size of the viscous material compared with the quantity of the complete manufactured product.

At present, two approaches are known for contactless measurement setups based on fluorescence [15]. The first approach is a measurement setup that functions on the principle of hyperspectral imaging [16,17]. A linear variable filter is used to generate, for each point in a defined measurement spot on the viscous material, the resultant fluorescence spectrum. The spectra are recorded using a 2D sensor array and analyzed with adapted algorithms. Disadvantages are the small spot size (1 mm^2) and the low speed (0.1–0.2 m/s) of the measurement object. The second approach is based on fluorescence imaging [18,19]. For evaluation, three similar images of the measurement object are filtered at different wavelength ranges. Owing to the use of 2D sensor arrays (resolution: 1024 pixel $\times$ 1280 pixel) and the related duration for the data transfer, the maximum speed of the measurement object is limited to 0.25 m/s. Thus, the achieved results only show good quality for stationary and slow-moving measurement objects. This approach enables innovative contactless detection of mixture ratios and impurities for fluorescing viscous materials at a maximum speed of 0.25 m/s. Both contactless measurement setups, however, are unsuitable for quality control in a manufacturing process, where the speed of the measured objects is up to 5 m/s.

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Beyond fluorescence imaging systems for the quality control of viscous materials, the functionality of the optical setup has also been proven in the field of medicine [20]. Similar setups have long been used for the detection of various types of cancer. One example is the detection of malignant lymph nodes in breasts [21].

This study presents an innovative high-speed measurement method based on the same fundamental idea as the previously described systems, wherein three similar fluorescence images of one measurement object are filtered and recorded. The main tasks of the imaging system are to detect the mixture ratios and impurities in a fast-moving measurement object during the manufacturing process. On the basis of the encouraging results of 2D fluorescence imaging measurements and the prolonged use in the field of medicine [18,21], the arrangement of the optical components (beam splitter and bandpass filter) and the effect of fluorescence are the premise for the high-speed quality control measurement setup. Hence, monitoring of measured objects at a speed of 5 m/s is possible such that industrial 1D senor arrays are used as recording devices. Owing to a one-to-one mapping, the size of the measurement object is $20\,\mu m \times 4\,cm$. The excitation source is a high-power light-emitting diode (LED) in the ultraviolet (UV) wavelength range. The measurement object for evaluation is grease, which shows significant information in its fluorescence signals within a limited wavelength range.

2. Materials and methods

This section covers fundamentals of the system presented in this study. First, the concept will be explained, followed by the measurement setup, system characterization, calibration, evaluation algorithms, and measuring process.

2.1. Concept

The developed measurement setup is an advanced form of the existing fluorescence imaging systems [18] and [21]. The innovative concept in the use of optical components is shown in Fig. 1. The presented setup enables the detection of mixture ratios and impurities in fast-moving fluorescing viscous materials during their manufacturing processes. The used optical components in the setup are designed for a maximum measurement object speed of 5 m/s. The realization is approached as follows. In all optical paths, the same fluorescence image of the moving measurement object is acquired. Each image is filtered at a different narrow-band wavelength range and recorded with an industrial 1D sensor array. For an appropriate fluorescence image acquisition, the measurement object has to be illuminated with the appropriate excitation wavelength. In this case, the number of optical paths is restricted to three. This limitation results from the characteristics of the viscous materials. The characteristics, quality, and necessary information of the viscous materials are mainly determined by three main components. Through the use of three optical paths in the measurement setup, an implementation of a clear and interpretable graphical visualization of the measurement results is also possible. During the graphical visualization all corresponding intensity values of the different images are merged into one vector and plotted in a coordinate system. Hence, the results can be represented in a graphical user interface.

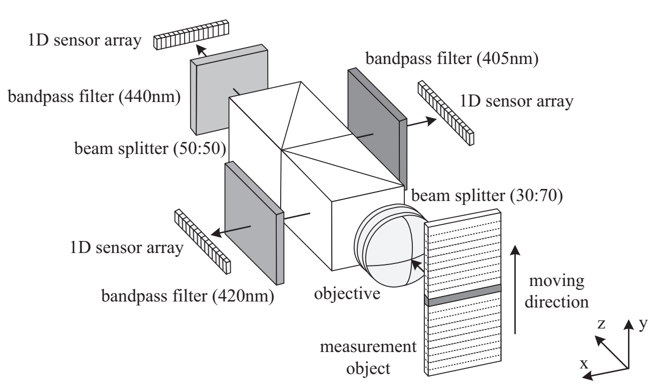

Fig. 1. Concept of a high-speed fluorescence imaging system: The fluorescence of the measurement object is imaged through a lens and passed through a beam splitter assembly into three optical paths. Subsequently, the fluorescence images are filtered at different narrow-band filters and recorded with industrial 1D sensor arrays. The maximum speed of the measurement object is 5 m/s.

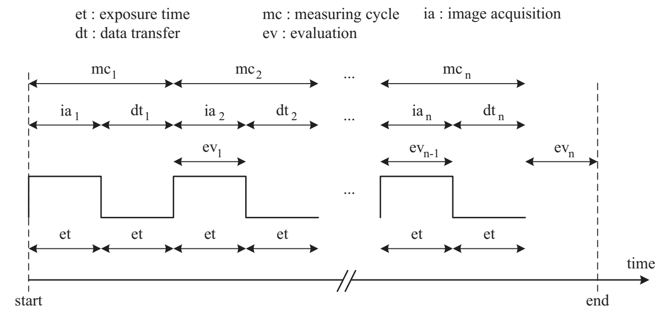

Fig. 2. Flowchart of a complete measurement procedure with acquisition, data transfer, and evaluation. The duration of a measurement cycle (mc) is two times the exposure time (et) of the 1D sensor arrays and is composed of image acquisition (ia) and data transfer (dt). The evaluation (ev) of the fluorescence image data is performed after every successful data transfer to the evaluation unit. The procedure works in real-time and is continuous.

Each measuring cycle consists of an image acquisition and a data transfer to the evaluation unit. The cycle structure is shown in Fig. 2 and described as follows. First, the 1D sensor arrays record data over the adjusted exposure time. Subsequently, the image data are transferred to the evaluation unit, so no image acquisition is performed yet. The entire duration of one measuring cycle is two times the adjusted exposure time. The acquisition and processing of the image data at the evaluation unit occurs simultaneously. Both procedures work continuously over the complete measuring process. Thus, online monitoring of viscous materials is feasible for industrial processes.

The evaluation starts after the first data transfer and is repeated each time new image data are received from the 1D sensor arrays. The evaluation objective is the detection of mixture ratios and impurities present in the viscous material. Impurities may include soot, dust, cuttings, and plastic particles.

The detection of impurities in the viscous material is implemented with a threshold algorithm. Here, each pixel value is compared with a reference value to determine, the existence of impurities in the considered viscous material. When the pixel value is beyond the defined range, it will be marked, and the maximum lateral size of the impurities can be determined. The proposed threshold algorithm works very quickly and sufficiently detects the impurities in the measurement object. Thus, the implementation of elaborate evaluation algorithms is unnecessary. The lateral resolution in the x direction of the current measurement setup is 10 μm. Determination of the y dimension of the impurities is not possible, because a fluorescence superimposition occurs during the acquisition.

The evaluation of the mixture ratios is realized through a defined acceptance range in a 3D coordinate system. Owing to the use of three different bandpass filters, each axis in the coordinate system represents the intensities of a different wavelength range. On the basis of the merged fluorescence image data, the number of vectors beyond the acceptance range can be calculated. Through