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INVESTIGATION ON A MODULAR HIGH SPEED MULTISPECTRAL CAMERA

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Abstract – Multispectral imaging grows in importance in an increasing field of image processing applications. The reason for it is that they provide substantially more spectral information than for example RGB (red-green-blue) colour cameras. For this reason a multispectral camera is designed and developed at the department quality assurance of the Ilmenau University of Technology. Based on well known approaches for filter wheel cameras, a new modular concept was developed particularly for high speed applications. For the complex control and correction computations thereby a field programmable gate array (FPGA) is used.

Keywords - multispectral, filter wheel camera, field programmable gate array, image processing

I. INTRODUCTION

Each viewed object or material is characterized by his unique spectral signature. This characteristic is based on the difference in reflection, transmission and absorption as a function of structural properties and substance. The advantages of multispectral imaging in comparing to RGB technologies emerge in the larger colour space. This opens a wide range of application fields in research, medicine and quality assurance.

Already in the 70's of the 20th century multi-spectral cameras were developed [1]. One of the oldest approaches was thereby the development of filter wheel cameras. These approaches were limited however by the state of the art of control engineering at that time. Limitations are the maximal number of colour channels and the increased acquisition time of multispectral images. Typical filter wheel based multispectral cameras consist of usually maximally seven filters and work with acquisition times of up to one second. The increased acquisition time results from the conception of multispectral image processing. The individual colour channels of a multispectral image are taken up sequentially by connecting an appropriate filter. These channels are joined by image processing technologies to a single image, which contains the entire spectral information. Current innovations involve the use of liquid crystal tuneable filters (LCTFs) [2].

Our optimization approach is based on the increase of the number of colour channels and the reduction of the acquisition. This is reached by the use of real time image processing on a FPGA, which takes over the synchronization of the control signals as well as the picture pre-processing.

II. PRELIMINARY WORK

A first important criterion was to investigate the inclination of the band pass filters in the optical path. For this purpose an experimental setup with a multispectral light source, several band pass filters and a spectrometer was assembled [3]. The band pass filters were positioned at various angles to the optical beam path and the spectrometer displays the appropriate outgoing wavelength (fig. 1).

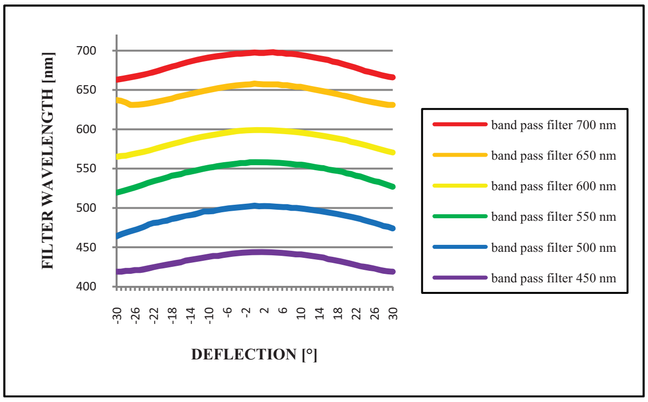

Fig. 1: Influence of inclination on outgoing wavelength [3]

The result shows inclination of band pass colour filters has significant influence to bandwidth of band pass colour filters. More specifically, it can be assumed per one degree of deflection from the orthographic optical path of the colour filter results nearly one nanometre deflection from the defined wavelength of the colour filter (table 1).

Table 1: Dependence of the effective filter wavelength to angular filter position

DEFLECTION [°] / WAVELENGTH [nm]	-2	-1	0	1	2
700	696,5	697,0	697,5	697,0	697,0
450	443,0	443,5	444,0	444,0	444,0
500	501,5	502,0	503,0	502,0	502,5
550	557,0	558,0	558,0	558,0	558,0
600	598,5	599,0	599,0	599,0	599,0
650	657,0	657,0	658,0	657,5	657,0

A deflection of 2 degrees in positive and negative direction of colour filter to orthographic optical beam path is used for further examinations.

This analysis was used among other things to define requirements for first conceptions and constructions of multispectral camera-prototypes (figure 2).

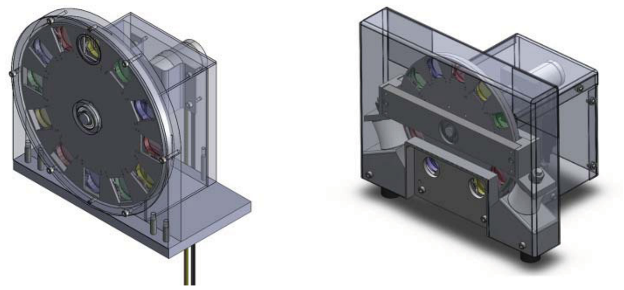

Fig. 2: Pre-prototypes

III. IMPLEMENTATION OF A MODULAR HIGH SPEED MULTISPECTRAL CAMERA

A. *Conception of a Modular High Speed Multispectral Camera*

The primary goal was the implementation of a multispectral camera, which take up 12 colour channels within a few milliseconds. Consequently an almost vibration-free modular concept was developed which consists of a filter wheel with a brushless direct current (DC) motor with motor control and a camera (figure 3).

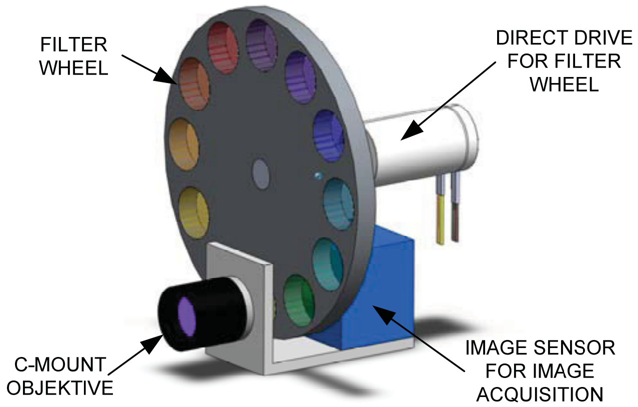

Fig. 3: Concept of the multispectral camera

The filter wheel is equipped with 12 band pass interference filters, which cover wavelengths from 334 nm to 1064 nm.

Furthermore the axle of filter wheel is full floating to compensate inner tensions and the used ball bearings are completely enclosed to avoid contaminants. The electrical drive of the filter wheel was selected due to its high accuracy at high speeds.

The technical data of the used image sensor is crucial for the properties of the modular high speed multispectral camera. At this point the modular design of the multispectral camera has significant advantages. The existing camera design is prepared to assemble and adjust different monochromatic CMOS (complementary metal oxide semiconductor) or CCD (charge-coupled device) sensors and customize the multispectral camera to different requirements.

A CMOS image sensor with a frame rate of 60 frames per second (fps) is currently assembled and thus creating a maximum dynamic up to 300 revolutions per minute (rpm). Overall, the permitted maximum speed of the multispectral camera construction is up to 3000 rpm], which would correspond to a theoretical image frame rate of up to 500 fps. These dynamic is supported by a weight-optimized and four-way rubber-mounted filter wheel. The finally developed and manufactured multispectral camera model is shown in Fig. 4.

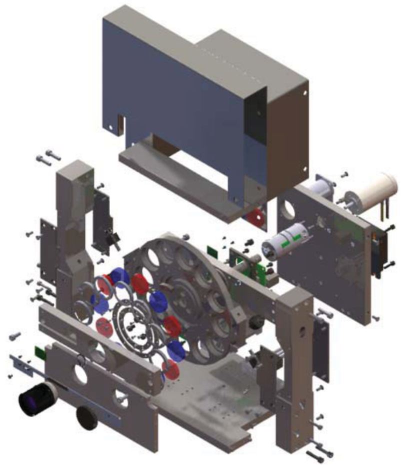

Fig. 4: Exploded view drawing of the modular multispectral camera

For threaded connection of the camera lens is chosen the prevalent C-Mount Standard. A major advantage of the C-mount Standard is the high level of international acceptance and the wide range of available lenses.

B. *Synchronization*

For the correct image acquisition the individual filters must completely cover the sensor surface during the integration time of the sensor. Beyond that boundary regions and filter mounting plate must not cover the sensor, since this leads to shadings. Therefore filter positioning and image acquisition must be synchronized.

Two possibilities are conceivable. On the one hand to adapt the frame rate as functions of engine speed and filter position. In this case, the image acquisition can be adjusted by an asynchronous reset, each time the middle filter position match the sensor position. Disadvantage here is that the maximum frame rate of the sensor is not utilized. A further possibility for the synchronization offers the dynamic regulation of the engine speed, with constant image frequency of the sensor. Thus the maximum frame rate can be used, however the control expenditure is larger.

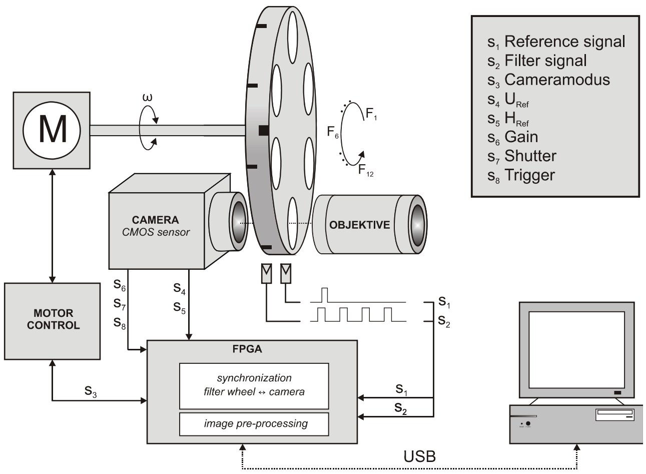

Fig. 5: Control and data signals of the multispectral camera

For the accurate synchronization the controlled variables engine speed, filter position and image frequency must be determined in real time. For the determination of the current filter wheel position two reflected-light barriers and a biunique coding were implemented on the filter wheel [S_1 and S_2 in figure 5].

The engine speed is determined directly over the motor control. The current number of revolutions of the brushless DC motor is supervised by a Hall sensor can be queried at any time. Accordingly a target number of revolutions can be specified over the motor control. Communication is serial RS232 [S_3 in figure 5].

The synchronization signals of the camera represent the frame and the line valid signal [S_4 and S_5 in figure 5]. On the other hand an asynchronous image acquisition can be initiated over the trigger line [S_8 in figure 5].

All measuring and control quantities are parallel supervised and regulated by the FPGA in real time. Both initially described control methods are to be examined and implemented. For the filter wheel camera a combination of both methods is conceivable, in order to adjust the mechanical start-up phase of the filter wheel and to synchronize later on maximum frame rate.

C. Features

Operators can decide between a “high speed record mode” with several multispectral images per second and a “high resolution precision mode” for higher quality images. These modes are realized on the one hand by the highly exact position able pass interference filters and on the other hand by the modular structure with individual sensors.

The current mounted monochromatic CMOS Sensor provides a resolution of 640x480 at 60 frames per second. This results a maximum filter wheel speed of 250 rpm, which is feasible only in high speed mode of the multispectral camera.

D. Difficulties in the implementation

Different types of band pass interference filters have different dimensions and lead to an imbalance at high speed of the filter wheel. The filter wheel is 4-way rubber-mounted to compensate these vibrations and the translational degree of freedom x is mechanical locked to avoid optical tipping.

The C-Mount Standard makes high demands on design of this multispectral camera. The distance between the flange of the lens thread and the sensor surface must be exactly 17.526 mm. The distance is substantial for construction of the filter wheel and for swinging the band pass interference filters into the optical path of the objective.

E. Further Work

Next tasks will be research on image tiling by highly dynamic correction of deviation in homogeneity and spectral concentration with band pass filters.

Furthermore calibration models for each several spectral colour channel will be developed, implemented and tested. Since for the filter wheel filters are used, which works on basis of angle-dependent interference phenomena, tilting lead to inhomogeneous wavelength coverage over the sensor surface (compare section II). For the compensation first the geometrical situation of the individual filters must be determined. This information forms the basis for a correction model, which corrects the spectral data of each channel. The computation takes place in real time on the FPGA.

Furthermore the stability of the used illumination will be investigated. Another feature of our multispectral camera is the feasibility to assembly a second camera module. This arrangement admits the existing Multispectral camera to convert into a stereoscopic configuration.

IV. CONCLUSION

Using most modern FPGA technology, the concept of filter wheel cameras was revised to exceed previous limitations of multispectral cameras. In combination with a modular structure, the camera can be adapted to different requirements. It represents thereby a cost effective sensor for multispectral measurements, which can also perform highly precise measurements through the use of correction functions. Therefore special difficulties had to be mastered, like the synchronization as well as the vibration response of the filter wheel.

V. ACKNOWLEDGMENT

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