# CLOSE RANGE PHOTOGRAMMETRY – STRUCTURED LIGHT APPROACH FOR MACHINE VISION AIDED HARVESTING

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**ABSTRACT:**

The following paper describes a novel data acquisition system for machine vision aided harvesting, which can also be used to provide data for various different applications. The system consists of two cameras and a projector. The basis for the operation is to project a pattern of structured light onto a target. By synchronous operation of the projector and the cameras, a dataset of imaged patterns can be produced. These images are formed of feature points, which can be used as input data for known photogrammetric measurement algorithms. (Luhman, 2006) As an arbitrary pattern can be projected, imaged and extracted from the background, the use of automatic feature point search is made feasible. The system is designed to work under challenging Finnish forestry conditions and is able to detect the projected pattern even in bright ambient sunlight by using spectral filtering and pulsed operation. In ideal conditions, this can be compared to using a flashlight in a dark corridor, offering the user a total control over the lighting.

## 1. INTRODUCTION

The paper describes a novel method of data acquisition for photogrammetric measurement system under challenging forestry conditions. Motivation behind the research is to be able to implement a machine vision aided harvester system capable of operating under any environmental conditions without compromising the already obtained harvester efficiency. The goal is to be able to measure all possible characteristics of an individual tree prior to touching it. If a 3-D model of a tree can be measured while approaching it, the model can be used to aid in the decision making on how to cut and process it. Further use of model data includes a database of all the trees cut. Using this kind of dataset for planning the next harvesting event is highly useful.

The requirements caused by the environmental conditions calls for a vast knowledge of not only photogrammetry, but imaging technology as well. As such, the paper will focus on the latter while keeping emphasis on what kind of data would be ideal for close range photogrammetric techniques. The actual photogrammetric measurement task is not described on this paper.

The data acquisition system consists of two cameras and a Digital Micromirror Device (DMD) based projector. By finding out the relative orientation of the cameras and keeping their orientation fixed, it is possible to use the projector to project a pattern onto the subject and use the image data recorded by the cameras for photogrammetric measurements using established methods. Alternatively, the projector can be included in the system orientation. This approach makes it possible to generate a virtual viewpoint from the projector location and use it for the measurement task as well. This effectively creates a data acquisition system consisting of three cameras. (Sen, 2005)

The reliable automatic measurement of the subject, such as a tree, requires either vast amount of processing power or suitably coded targets. The proposed method aims to produce a set of images in a binary form, in which the subject points are ones, and background zeroes. The approach is similar to a laser line scanner. The image elements which are part of the line are ones and others zeroes. In this regard, the research is about extending proven static structured light methods into a dynamic system. This is made possible by a DMD-chipped projector as it is capable of projecting an arbitrary pattern, so the line scan approach becomes just one possibility in an infinite set of patterns. This combined with a pulsed mode operation to ensure high temporal intensity on the target leads to a highly versatile system, giving possibilities for wide range of implementations for various applications in the field of close range photogrammetry. (Luhman, 2006)

## 2. PRINCIPLES OF OPERATION

The proposed approach for acquiring measurement data suitable for photogrammetric techniques is made challenging by the environmental conditions present in the harvester operation area. Probably the most challenging aspect to overcome is the lighting, as the pattern projected onto the subject has to be more intense than the ambient light. This leads to the worst case scenario where the intensity of the projected light should exceed the intensity of the sunlight during a bright summer day. Other environmental variables include rain, snow, leaves, branches, vibration etc.

The problem is solved by pulsed mode operation and spectral filtering. The projector will use LEDs driven with a high current in pulsed operation to achieve high temporal intensity on the subject. DMD-based projection technology is proposed, because its reflective operation allows for a minimal light loss during the projection. This approach is crucial, as the harvester has to retain its normal operation. So the data capturing has to be done in real time, which leads to the need for short integration times of a fraction of a second to efficiently stop the motion. Short integration time also enhances the relative intensity of the structured light compared to ambient, leading to more effective spectral filtering. The method could be compared to high speed flash photography, which is often used to produce a black background in macro photography.

Spectral filtering includes finding out the wavelength band, where combination of the sensor response, reflectance of the target and ambient light intensity produce best possible imagery. This means highest possible contrast between the projected data points and the background.

## 3. SYSTEM SETUP

The data acquisition system consists of three parts: two cameras and a projector. The projector and cameras are mounted on the harvester head. The actual positioning depends on the harvester head model. The goal is to have as large base as possible between the cameras to provide a good geometric accuracy for resection observations. The projector should be positioned between the cameras, but its exact place is not important unless it is calibrated to act as a virtual camera by including it in system calibration as described later.

Placing the capture devices on the harvester head offers a good view of the scene. Because the head can be moved freely, the imaging system can be rotated to offer various viewpoints for enhanced geometric accuracy. The mechanical robustness of the head on the other hand is very good and as such offers a solid base for the system. This improves the stability of the relative orientation, leading to less frequent calibration intervals. However the harvester head is prone to receiving quite pronounced shocks and bumps while operating in the forest. Environmental conditions such as this require that the moving parts of imaging devices are kept at absolute minimum and they need to be extremely resistant to vibration and shock. In addition, the system should be able to withstand high moisture and temperature changes.

Implementing a DMD-projector based system in this kind of environment might seem quite bold, but the DMD-chip is actually very robust. It is able to tolerate vibrations of 20g with 2000Hz frequency and mechanical shock up to 1500g. (Douglass, 2003) The cameras used should be equally robust. This can be achieved by using electronic shutter. It eliminates the need for a mechanical shutter, which could fail under challenging conditions. Additionally, the optics should be fixed with locking screws to ensure the stability of the optical system, reducing the need for frequent system recalibration.

### 3.1 Spectral considerations

DMD is a technology developed by Texas Instruments. It is the core part of DLP, or Digital Light Processing system. DMD-chip consists of an array of up to 2 million hinge-mounted microscopic mirrors. Each mirror can either reflect light through the optics onto the target, or reflect the light to the heatsink. This essentially means that by using DMD-chipped projector, it is possible to project an arbitrary binary pattern of up to 2 million elements onto the target. Because the mirrors are reflective, the light loss of the system is minimal. In this study a consumer grade projector with 800x600 elements is used. (Douglass, 2003)

In consumer market, the reflective operation makes it possible to produce a projector which uses LED-backlights. This approach eliminates the need of a color filter wheel to produce the colors, as it is possible to use three LEDs with suitable spectral characteristics for color reproduction. Because of the relatively monochromatic nature of LEDs, an optimal projector screen which reflects only the narrow wavelength ranges of the chosen LEDs can be manufactured. This leads to improved contrast.

The same principle can be used in scientific imaging. The LED-backlights of a consumer grade projector can be replaced with suitable LEDs while using optical bandpass filtering in the camera to attenuate the ambient light outside the chosen band. This results in enough contrast between the projected data points and the background illuminated by the leftover ambient light.

The available LED wavelengths are 850nm, 870nm, 905nm and 950nm. In this study, the wavelength of 905nm is considered. The wavelength is chosen by comparing the spectral response of the sensor and the reflectance of bark and needles. The optimal situation is, when the sensitivity of the sensor and the reflectance of the bark are high and the reflectance of the needles is low. The preliminary tests are measured with the ASD Field Spec Pro FR and show the spectral reflectance of coniferous tree bark and needles.

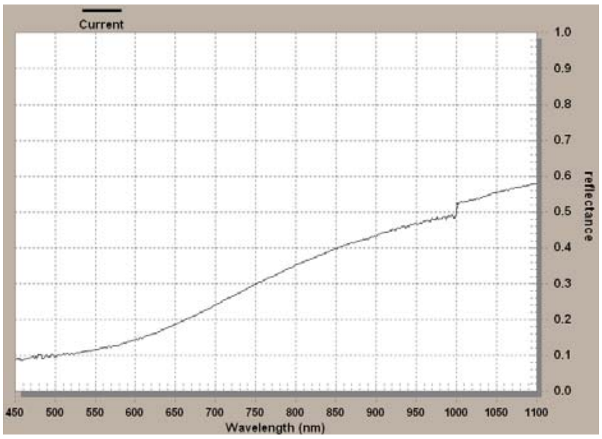


Figure 1. Spectral reflectance of coniferous bark

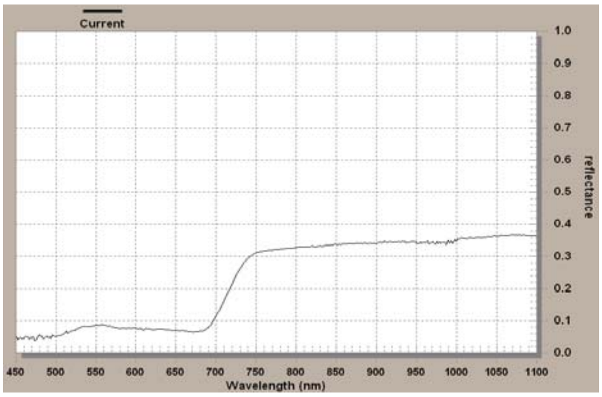


Figure 2. Spectral reflectance of coniferous needles

From the Figures 1 and 2 we can see that the reflectance of the needles stay quite uniform in the NIR-band while the reflectance of the bark continues to rise steadily. From this observation we can conclude that it would be more feasible to use 950nm band rather than 905nm. However, the sensitivity of the sensor drops rapidly as a function of the wavelength as can be seen from the sensor response graph provided by the manufacturer in Figure 3. Also, the filtering of the 950nm band proved more difficult than the 905nm band. The chosen camera, SMX-150M-E implements the IBIS5B NIR sensor with enhanced spectral response in the NIR-area due to a thicker epitaxial Si layer. (Sumix Corporation, 2007)

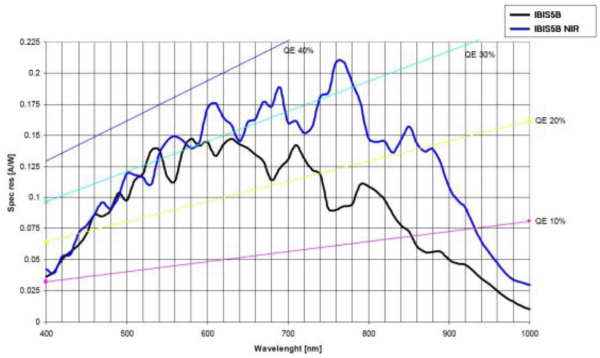


Figure 3. Spectral response of IBIS5 sensor (Sumix Corporation, 2007)

Aspects such as the harmfulness of the radiation used and its influence on the surrounding environment must be considered as well. Visible light can be used, but the frequent flashes of light on the subject during operation could distract the harvester driver. Thus the use of the NIR-wavelength area is proposed as it is invisible for the human eye. The use of LEDs as light source instead of lasers is also important for eye safety reasons. A projector equipped with a NIR LED backlight projects a non-coherent light pattern, which does not suffer from interference problems and is safe to use.

To find a correct bandpass filter, the spectral output of Roithner Lasertechnics H2W5-905 LED is measured. The results are shown in the Figure 4.

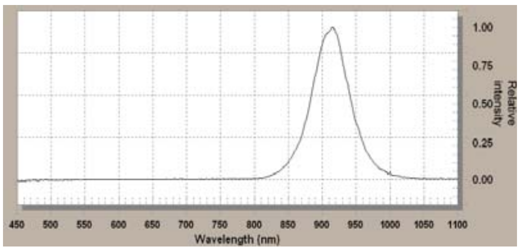


Figure 4. Spectral intensity of H2W5-905 LED

In the current stage of the project, it is feasible to produce suitable bandpass filter by combining short- and longpass interference filters. For the 905nm band, Edmund optics #48-561 and #47-588 filters are used and transmittance measured as shown in the Figure 5.

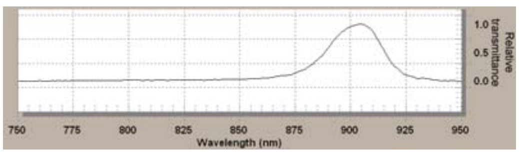


Figure 5. Spectral transmittance of 905nm bandpass

From the Figure 5 we can see that the passband is centered quite precisely at the wavelength of 905nm, making the filter combination highly suitable for the chosen LED.

The spectral intensity of the ambient light in forest environment also affects the choice of the band. Ambient light is strongly influenced by the atmospheric absorption. The absorption characteristics of the water vapor are especially important as they are very pronounced at 905nm. This results in attenuation of the ambient light on the subject, leading to a more efficient use of the structured light.

### 3.2 Pulsed drive circuit

To operate the LED and the camera in pulsed mode operation, a special drive circuit is needed. The goal is to first light up the LED and when it reaches its maximum intensity, the integration should begin. Shortly after the set integration time is met, the LED is allowed to turn off. For this application, the following prototype is implemented.

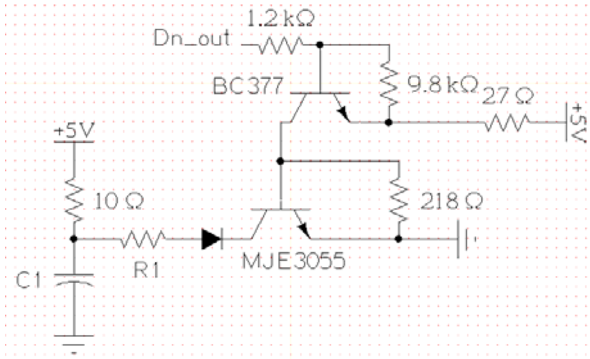


Figure 6. LED flash circuit

The Figure 6 shows a circuit consisting of two transistor switches. The MJE3055 controls the charge stored in the capacitor while the BC337 controls the signal needed to saturate the MJE3055 to release the charge and light up the LED. The circuit is connected to a computer which provides the power via an USB-port and timing signal through LPT-port. The LPT-port is connected to Dn_out as indicated in the circuit schematic. 5V USB power line is used to charge the capacitor and also to saturate the MJE3055. BC337 is saturated by the LPT-port data pin. The same data pin can be used for the external trigger of the SMX-150M-E camera. This results in a synchronized operation of the camera and the LED. The capacitance of the C1 can be varied according to illumination requirements. To maintain the high current drive for the LED, the current prototype uses combination of four capacitors for the total capacitance of 19mF.

The theoretical peak drive current of the LED can be calculated using the following formula:

$$I = \frac{U}{R} \tag{1}$$

where I = current
U= voltage
R= resistance

The circuit has been tested with theoretical peak current up to 8.3A by using a 0.6 Ω value for R1. This causes LED to be driven with a peak current well above the specification to produce highest possible temporal intensity, enhancing the visibility of the structured light on the target. With the present implementation, the shortest possible LED pulse is 50ms, which ensures that the LED is lit up for the whole integration time of the camera, yet short enough to keep the risk of LED failure due to thermal management low. The camera parameters on the other hand can be freely modified within the specifications, giving the shortest integration time of 3µs. In practice, the reasonable operation range is 1-10ms.

## 4. RESULTS

The system components are only tested separately at the current stage of the project and as such the results reflect the operation of each individual part of the system. Results should be treated as preliminary and used to give insight on how the system should be implemented as a final product.

### 4.1 Pulsed operation and spectral filtering

The pulsed operation is tested by using the circuit described in the chapter 3.2 together with the 905nm spectral filtering and the SMX-150M-E camera. The H2W5-905 LED is used in pulsed mode operation at theoretical peak current of 8.3A using a 50ms flash duration.

The exposure value for the camera is nominated by directing it to take a picture of a tree through a window glass. The integration time is varied until the shot is correctly exposed, resulting in the highest luminance value of 240 out of the scale of 1-255 with a integration time of 3ms. The corresponding pixel is a reflection from a deciduous leaf at a sunny summer day.

Next, the camera is pointed towards a dartboard, which is lit by a 1000W photographic spotlight. The exposure is varied by altering the distance of the spotlight from the dartboard until the highest recorded luminance value is 240. Camera parameters are kept the same. This results in the same intensity on the dartboard than the previous reflection from the leaf.

The camera is set to external trigger mode and triggered together with a H2W5-905 LED, which is aimed at the target by the means of 250mm F4 Leitz Telyt-R lens that produces a beam of light of approximately the same diameter as the dartboard target. After the exposure, the same photo is taken again without triggering the LED. The second photo is counted as a dark frame data and is subtracted from the first.

Figure 7. Ambient light elimination test

In the Figure 7, we can see the dartboard illuminated by the LED. There is still some leftover ambient light in the form of interference rings. These artifacts could be filtered away in post processing, but are left here for illustrative purposes. By taking a picture of the same target with two cameras synchronously, the resulting data could be used for photogrammetric measurement tasks, if the relative- and internal orientations of the cameras are known.

### 4.2 Structured light pattern test

An unmodified Voigtländer DLP200 projector is used for illustrating the operation of the structured light. The projector is used to project a test pattern of vertical stripes of white light onto a coniferous tree trunk in a dark lighting. The stripes are recorded by an Olympus E-330 camera with a 11-22mm Zuiko Digital lens set to 11mm focal length.

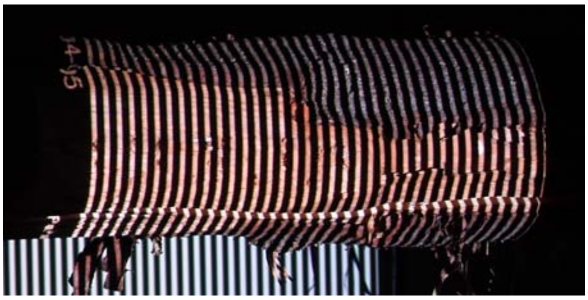

Figure 8. A coniferous trunk illuminated by DLP-projector

The photo is then enhanced by finding the edges of the projected stripes and marking each pixel consisting of a stripe with “1” while leaving other elements “0”.

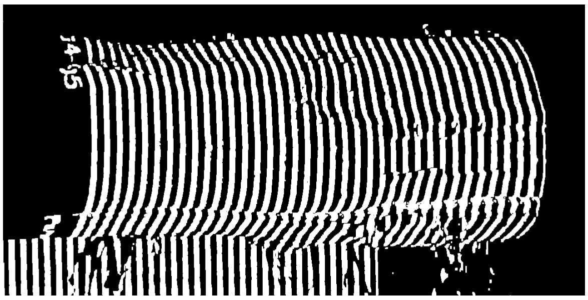

Figure 9. A binary image for on-line measurement

Resulting picture is a binary presentation of the vertical scan lines. The format greatly reduces the time required to find corresponding features from a stereo image pair by automated search methods. This makes implementing an automatic photogrammetric measurement system easier and by giving the user a choice over an infinite set of projection patterns makes the system highly suited for various tasks.

## 5. CONCLUSIONS

Judging from the preliminary test data, the system components work as planned. The next step would be combining them into a complete prototype system and running a set of real world tests in a forest condition, starting from sparse coniferous woods. The work includes replacing the backlight of the DLP-projector with high power 905nm LEDs driven by the circuit described in chapter 3.2 and mounting the cameras and the projector on the harvester head. Relative- and interior orientation for the cameras should be calculated once they are mounted and secured.

The main problem with the implementation is probably the light loss caused by spreading the light pattern onto wide enough FOV (Field Of View). The projector should offer the same FOV as the camera to take full advantage of the imager. However, this would restrict the choice of the focal length of the camera. To overcome the problem, the projector can be equipped with a zoom lens, letting the user to produce higher intensity per square unit while still offering a choice to illuminate a wide FOV. The cameras should not be equipped with zoom lenses as they tend to lose their calibration rather easily and even in best case require multiple sets of calibration parameters to ensure a proper interior orientation when changing the focal length.

In this application, the projector should not be included in the system calibration. Because the harvester operates in the forest, the projector focus should be changed according to the target distance to provide a sharp pattern of structured light on the target. The focus distance can be found out by using a laser scanner already implemented in the harvester. By excluding the projector from the system calibration, it can be used for on the field calibration of the camera system by projecting a calibration target with the projector and using it as the calibration input data.

### 5.1 References

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