Spectral signatures of surface materials in pig buildings

by
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ABSTRACT

Manual cleaning of livestock production buildings is widely based on high-pressure water cleaners. The work is unappealing to workers, because it is one of the most tedious and health threatening tasks to be conducted in agriculture. The cleaning process itself contributes to deterioration of the working environment due to the stirring up of dirt and micro organisms, which is inhaled by the operator.

Robotic cleaning often entails subsequent manual cleaning. The robot needs to detect the cleanliness of surfaces in order to minimize time for cleaning and the amount of water and electricity consumed. The development of an intelligent sensor for autonomous cleaning is a great challenge for agricultural engineers. How to catch the cleanness information on the different type surface is one of the major issues.

A hypotheses is that the reflectance of clean and contaminated building materials is different in the visual or the near infrared wavelength range. Therefore, the optical properties of surfaces to be cleaned and the different types of dirt found in finishing pig units were investigated in the VIS-NIR optical range. Reflectance data was sampled under controlled lighting conditions with a spectrometer communicating with a PC. The measurements were performed in a laboratory with the materials used in a real pig house for 4 to -5 weeks. The spectral data was collected for the surfaces before, during and after water cleaning.

The results support the hypotheses that the reflectance of building materials and contamination is different in the visual or the near infrared wavelength range. The spectral signatures indicate that the surface materials and dirt attached to the surfaces can be identified in certain spectral ranges. The analysis showed that it is possible to make a statistically significant discrimination and hence classify areas that are visually clean. A scenario with multi-spectral analysis, combined with appropriate illumination or camera filters is therefore being pursued. That provides the possibilities to apply a CCD camera with defined filter or light source to detect the surface cleanness.

Keyword: Automatic cleaning; cleanliness sensor; robot; reflectance; spectrometer

Introduction

Manual cleaning of livestock production buildings is widely based on high-pressure water cleaners. The work is unappealing to workers, because it is one of the most tedious and health threatening tasks to be conducted by humans (Strøm et al., 2003). The cleaning process itself contributes to deterioration of the working environment due to the stirring up of dirt and micro organisms, which is inhaled by the operator.

Robotic cleaning often entails subsequent manual cleaning. The robot needs to detect the cleanliness of surfaces in order to minimize time for cleaning and the amount of water and electricity consumed. The development of an intelligent sensor for autonomous cleaning is a great challenge for agricultural engineers.

How to catch the cleanness information on the different type surface is the major issue. One hypothesis is that the reflectance of building materials and contamination is different in the visual or the near infrared wavelength range. Therefore, the optical properties of surfaces to be cleaned and the different types of dirt found in finishing pig units were investigated in the VIS-NIR optical range.

Materials and Methods

Samples of building materials used in finishing pig production buildings were used for basic studies on their spectral signature in VIS-NIR optical range. In practice, a number of different materials are used in pig housing. In this study, four commonly used materials in pig building inventory were selected, namely concrete, plastic, wood and stainless steel. Concrete is widely used for solid as well as slatted floors and in some cases also for partition walls. Plastic is gaining popularity for partition walls at the expense of wooden partitions.

The most predominant material used for floors is concrete, an inorganic material. The manure and the contaminants may thus be spotted as organic material on inorganic background. Use of spectrometry in combination with special lighting may thus be a possibility to detect non-clean areas. The same would be true for housing equipment of stainless steel which is often used for drinkers and feeders.

Plastic panels are gaining ground for partition walls. Plastic is basically an organic material with other properties than the contamination. The plastic panels are generally delivered with different colours. Wood is also an organic material that is found as material for partition walls with painted surfaces in colour.

Spectrometer

The spectrometer used was a diffraction grating spectrometer[1] with a 2048 element CCD (charge-coupled device) detector that covered the spectral range from 400 to 1100 nm. It used a 10 µm slit, giving a spectral resolution of 1.4 nm. The detector integration time may be controlled by software in the range from 4 to 4000 milliseconds. This range, which is equivalent to A/D (Analog to Digital) data acquisition rates of 500 kHz down to 1 kHz. The 12 bit A/D converter gave a dynamic range from 1 to 4096 counts for any given detector integration setting. The signal to noise ratio was 1000:1. The spectrometer was connected to a portable PC via a USB-2 cable.

The light source used was a Tungsten-Krypton lamp[2] with colour temperature of 2800K, suitable for applications in the range VIS-NIR from 350 to 1700nm.

[1] EPP2000-VIS, StellarNet Inc., USA
[2] SL1, StellarNet Inc., USA

A Y-type armoured fibre optic reflectance probe, with 6 illuminating around 1 read fibre each being 400um in diameter and specified for VIS/NIR applications was used to connect the light source and the spectrometer to the probe head. The probe head was placed in the cavity of a sensor block as shown in figure 1. The sensor block was made of black plastic with dimensions 100 mm long, 50 mm wide and 37 mm high. The block had a 13 mm deep circular cavity with diameter 42 mm for the sensor head to be maintained in a desired distance and position relative to the sample surface and to avoid un-desired illumination effect. In the experiments, the sensor head was keep at 45º and a distance of 6 mm to measured surfaces. The vertical hole was covered with a black tape to avoid external light effects.

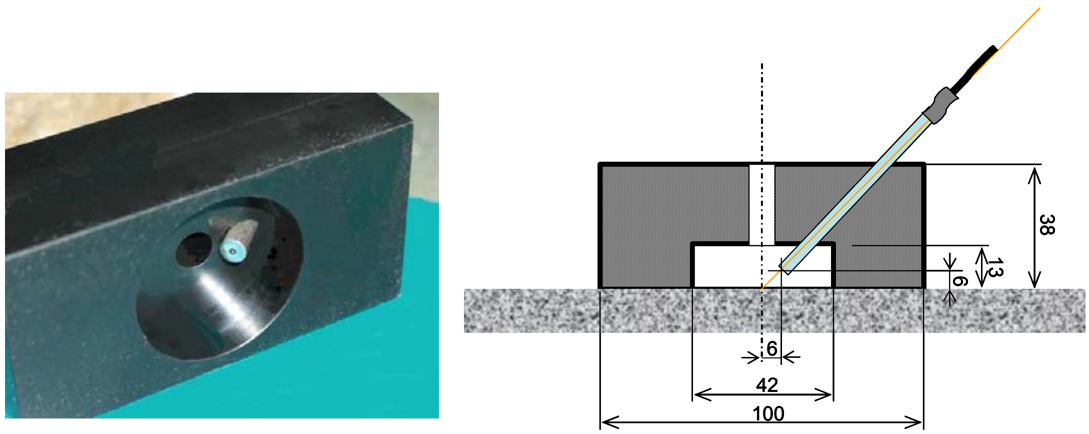


Figure 1. View and dimensions of sensor block. Dimensions are in millimetres.

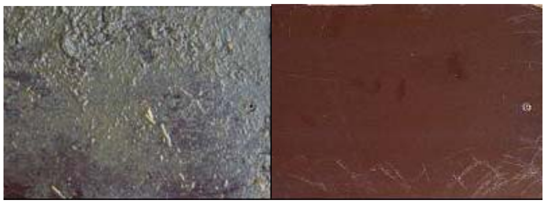
Experimental design

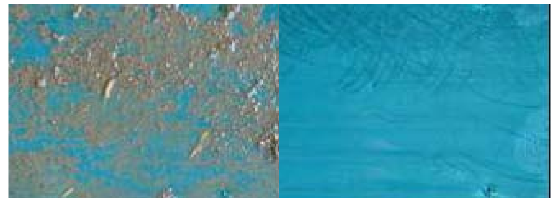
The measurements were performed in laboratory level. Small samples of plates of the different materials were placed on the floor and on the partition walls in a pig pen. After 4-5 weeks the test plates were brought into the laboratory for investigation. Figure 2 shows the photos of the four materials in wet condition before and after cleaning.

Spectral data were sampled for both dirty and cleaned plates in both wet and dry conditions, giving a total of 16 measurement setups, as listed Table 1. For each measurement setup spectral data were sampled in **20** randomly selected positions in order to include the effect caused by the non-homogeneous property of the surfaces. At each position, the reflectance data was recorded as an average of 5 scans with 2 seconds integration time to minimise signal noises. The values of the reflectance in the measured spectral ranges were used as the spectral signatures of the materials under the defined conditions.

Table 1.Measurement set-ups in laboratory:

Surface Type	Clean dry	Clean wet	Dirty dry	Dirty wet
Concrete	x	x	x	x
Plastic	x	x	x	x
Wood	x	x	x	x
Steel	x	x	x	x

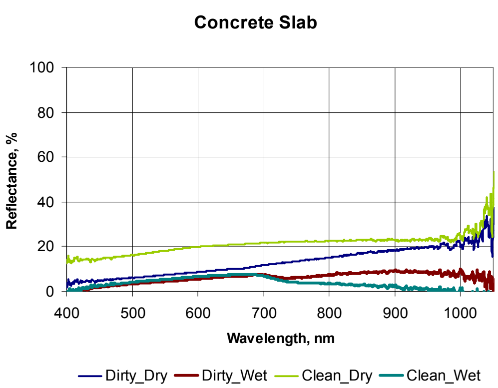




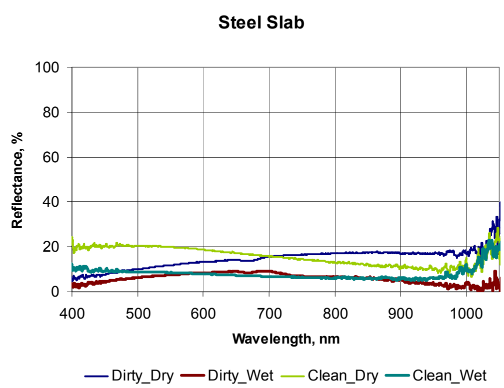
(a) *(b)*

(c) *(d)*

Figure 2. Photos of the materials in wet condition before and after cleaning: (a), wood plate; (b), plastic plate; (c), concrete slab; (d), steel plate.



(a)



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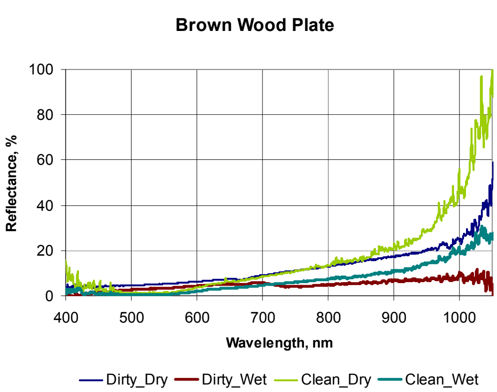
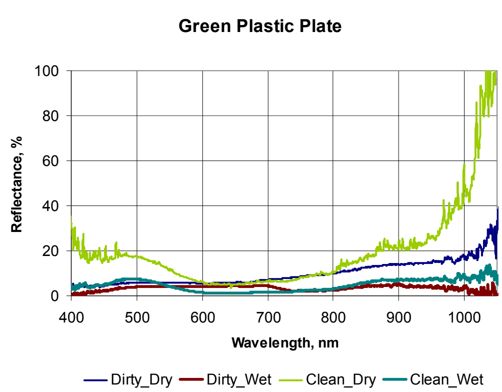


(c)



(d)

Figure 3. Average spectral data for the four selected materials before and after cleaning in dry or wet condition.

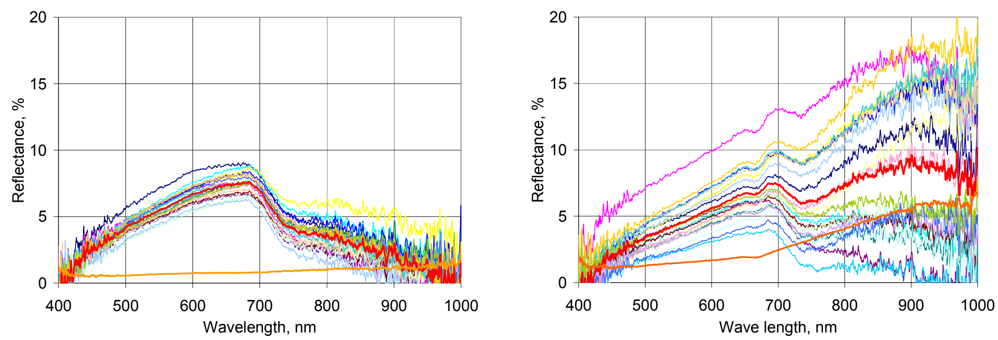
Results and discussion

Spectral signatures

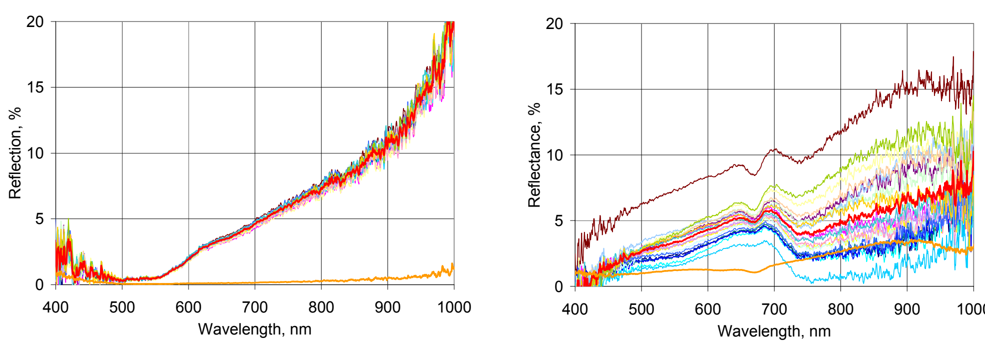
The primary results of the measured reflectance are shown in Figure 3. The curves were average values of the measured data in the 20 random points for each measurement set-up.

For concrete, under wet condition, a significant difference may be seen in wavelength of 750 – 1000 nm, figure 3(a). For stainless steel, however, the differences are seen in the wavelength ranges 400-500 and 950 – 1000 nm, figure 3(b). For the brown wood plate, figure 3(c), the reflectance under dirty-wet condition was higher in the wavelength ranges 500-700 nm and lower in 750- 1000 nm compared with in clean-wet conditions. For the green plastic plate, figure 3(d), the reflectance under dirty-wet condition was lower for wavelength below 550 nm and above 800 nm, but higher in wavelength between 600-700 nm compared with in clean-wet condition. In all these wavelength ranges, where lager differences were found, there are some potential to be useful for classification of clean and dirty.

Although wood and plastic are organic materials, the contaminants on these surfaces might be identified in some defined spectral ranges. The colours and densities of the background materials and dirt on the surfaces were the major reason to the differences of the reflectance in certain wavelength regions.



(a) Grey concrete: left, clean; and right, dirty.



(b) Brown painted wood: left, clean; and right, dirty.

Figure 4. Spectral data and the standard deviations of the grey concrete and brown wood slabs in wet conditions, —, average and —, standard deviation.

Figure 4 shows all measured reflectance data in the 20 measurement points and the standard deviations for the concrete slab and the brown wood plate in wet conditions. Comparing the curves in clean and dirty conditions, it can be seen that the standard deviations of these reflectance data in the dirty conditions were larger than in the clean conditions, especially in the near-infrared regions. That was caused by different degree of dirt attached on the surface with different thickness and smoothness. A large deviation may increase the difficulty to identify the clean and un-clean area.

Another interesting result that should be noticed in figure 4 is that the standard deviations for the concrete slab and the wood plate were also in different levels. The standard deviations for the painted brown wood plate were much lower in entire wavelength ranges of 400-1000 compared with the concrete slab. That indicated that the surface of the painted wood plate had more homogeneous property than the concrete slab.

Possibility to utilise CCD camera and multi-spectral image analysis method

The measured results of these spectral signatures indicate that the surface materials and dirt attached to the surfaces can be identified in certain spectral ranges. That opens for the possibilities to apply a CCD camera with defined filter or light source to detect the surface cleanness. Since both CCD camera and VIS-NIR spectrometers are based on CCD array technology, theirs sensibilities/relative responses in visible and near-infrared spectrums are similar. A spectrometer applies a line sensor array (one dimension) while a camera applies an area array (two dimension). Figure 5 shows a typical sensitivity/response curve of a CCD sensor array. The maximum sensitivity range varies from a blue range around 450 nm to a red around 600 nm, depending on the types of CCD sensors. Many of them are able to catch information in the NIR range up to 1000 nm.

A spectrometer is designed to use each sensor in a line array for a specific wavelength range to characterize a measurement point. An individual sensor provides the information related to a well defined wavelength in the range that the spectrometer covered.

A CCD camera is using a sensor array to a measurement area that focused on. An individual sensor provides the integrated information related to entire wavelength range on a part of the measured area. The information achieved by a CCD camera therefore is very dependant on the filter or the illumination used. That means, to provide information in a defined spectral range, a pre-defined filter or illumination is necessary.

By using the acousto-optical tunable filter (AOTF) method, a set of spectral images may be achieved in the defined spectral bands (Cupta et al., 1999). However, this is a rather expensive solution. An alternative is to select a few spectral bands based on the spectral characteristics achieved in the signature measurements and to apply the filters or illumination in the defined spectral range to a CCD camera. For the most considered material, concrete, for example, the clean and dirty area may be identified by the reflectance information in the spectral range of 650 nm and 800 nm. That can be demonstrated in figure 6, where the clean and dirty areas for concrete and brown painted wood are clearly separated in the two spectral channels in wet condition.

The analysis showed that it is possible to make a statistically significant discrimination and hence classify areas that are visually clean. A scenario with multi-spectral analysis, combined with appropriate illumination or camera filters is therefore being pursued.

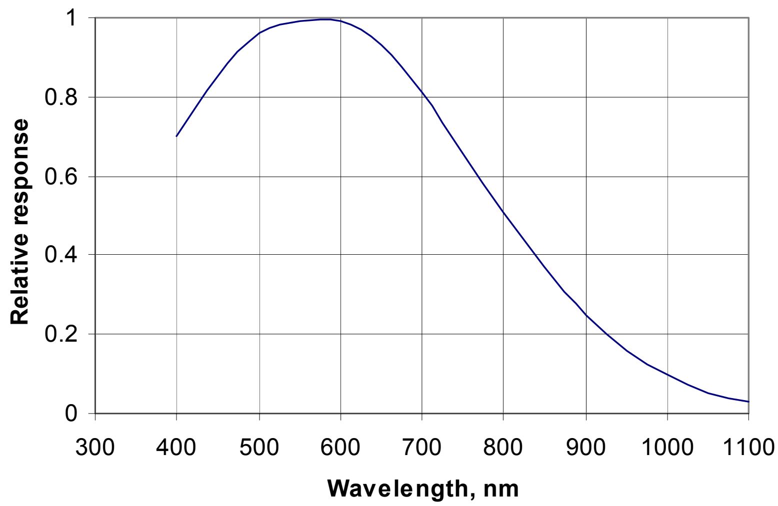


Figure 5. A typical sensitive curve a CCD sensor array for spectral meters and CCD cameras

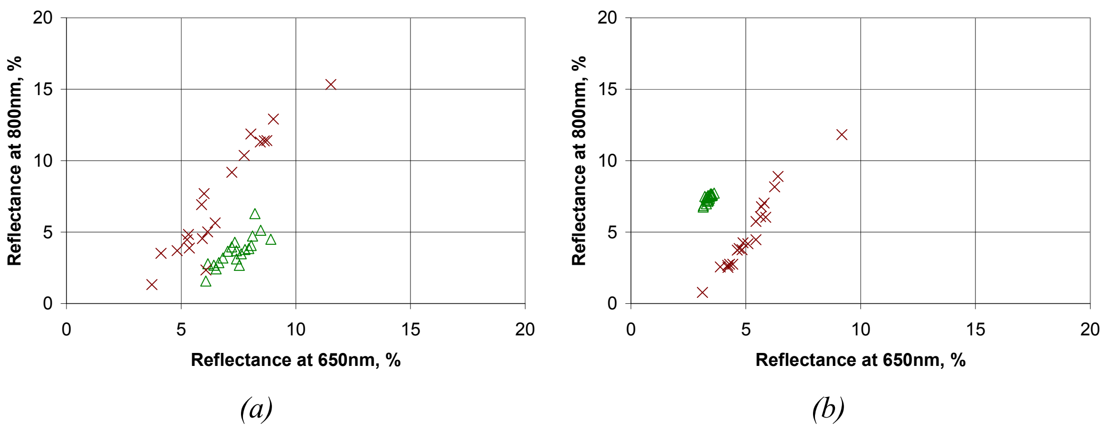


Figure 6. Reflectance for concrete and brown wood slabs at wavelength 800 nm versus 650 nm, in wet condition, where, Δ, clean and x, dirty.

Conclusions

The optical properties of surfaces to be cleaned and the different types of dirt found in finishing pig units were investigated in the VIS-NIR optical range. The results support the hypotheses that the reflectance of building materials and contamination is different in the visual or the near infrared wavelength range.

The results of spectral signatures indicate that the surface materials and dirt attached to the surfaces can be identified in certain spectral ranges. The analysis showed that it is possible to make a statistically significant discrimination and hence classify areas that are visually clean. A scenario with multi-spectral analysis, combined with appropriate illumination or camera filters is therefore being pursued. That provides the possibilities to apply a CCD camera with defined filter or light source to detect the surface cleanness.

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