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Asparagus spears – Quality you can hear

At present, conventional automated sorting systems do not allow the detection of hollow asparagus spears, which represents a severe internal quality defect, with reasonable certainty. Therefore, the following article deals with a newly method based on acoustic resonance analysis, which is potentially capable to distinguish hollow spears from sound. Thus, representing a valuable supplement to existing visual inspections.

Keywords
Asparagus spears, acoustic resonance analysis, non-destructive

Abstract
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Marketing of fruits and vegetables depends on valid EU standards. In the case of white asparagus spears, the existence of caverns inside a spear is a non-acceptable quality defect. In years with long and cold winter, up to 50% of the yield can be hollow and should be rejected. To facilitate the sorting process, fully automated machine vision systems are applied for visual inspection. Torn or double spears as well as spears with club-shaded growth can be reliably detected; however, spears with caverns but without abnormal growth still cause considerable problems.

In the frame of a project supported by the Federal Office for Agriculture and Food (BLE), the Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB), in cooperation with two SME (RTE Akustik + Prüftechnik GmbH (Pfinztal) and HMF Hermeler Maschinenbau), developed a sensor system for non-destructive, objective and fast detection of hollow spears. The system is based on acoustic resonance analysis in audible frequency range. Thus far, this method was applied for technical products, e. g. automatic defect recognition of clay roof tiles [1] and should be transferred to asparagus spears. The applicability of acoustic methods to describe ripeness or textural properties of horticultural products has been shown in various experiments [2]. The "impulse response technique", in particular, can be used to measure the elastic properties of apples, plums, tomatoes and the sensory attributes of carrots [3,4,5,6]. With this method, a short impact causes the products to vibrate. The vibration response is measured by an acoustic sensor (e. g. microphone) and resonance frequencies are determined by fast Fourier transform. Despite the frequency position, which is influenced by the product elastic properties, density, size or shape, further components contained in the signal such as the amplitude, provide information about product attributes [7].

Question

In respect of the constructional specifications of an available automatic asparagus grading machine of the project partner Hermeler Maschinenbau, some technical requirements had to be considered in the development of a functional model. **Figure 1** shows a section of the automatic asparagus sorter used for the experiments. There, the asparagus spears are lying separately in sorting trays that are attached to a horizontally running conveyor belt.

The objectives of this study were:

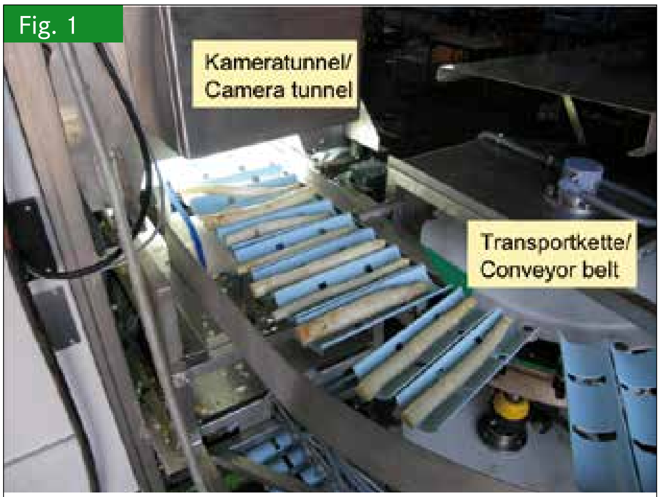
- to elevate the spears and detect acoustic signals independent of disturbing noise from tray or machinery
- to realise broadband vibration excitation without causing injury and
- to evaluate which kind of acoustical sensors are well-suited to detect the vibration.

Furthermore, algorithms were examined to correlate acoustic data and hollowness of the asparagus spears both under laboratory and practical conditions.

Test execution

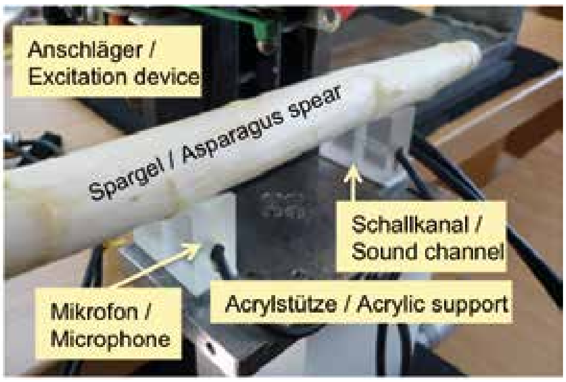
For experiments, a new sample holder was developed. It consisted of a metal base plate and two acrylic wedge-shaped supports that were connected to a both horizontally and vertically movable transport carriage running parallel to the conveyor belt. Slots in the conveyor trays enabled the acrylic supports diving through the trays to lift the asparagus spears. For sensing vibration mini electret condenser microphones were placed within the acrylic supports (**Figure 2**). A second setup used pressure-sensitive piezo film sensors, which were glued between the metal plate and the acrylic supports to measure the structure-borne sound. Two completely different excitation mechanisms were developed for electromechanical vibration stimulation. The first mechanism used a tiny hammer with a spherical metal head to excite the asparagus spears centrally from above. The second

Fig. 1



Part of an automatic asparagus sorter (Foto: M. Geyer)

Fig. 2



Functional model: Acrylic supports with integrated electret microphones (Foto: J. Foerster)

one used a midget solenoid that was installed in the perforated acrylic support. The plunger of that solenoid hits the asparagus spear at the basal end from below. This construction allows only one sensor for vibration measurement at the top of the spear.

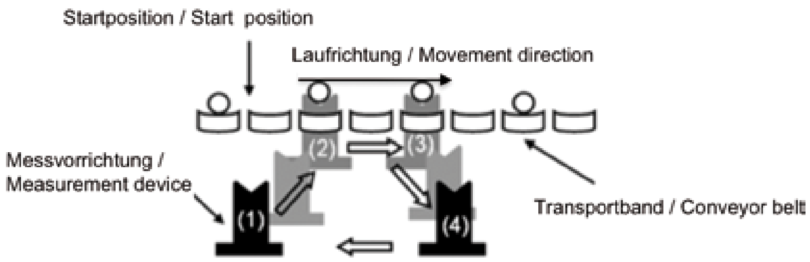
Applied scanning laser vibrometry proved that functional models enabled free vibration of asparagus spears and captured oscillations adequately [8]. Consequently, serial tests with hollow and sound asparagus spears were carried out. Under laboratory conditions 326 asparagus spears were placed on the sample holder randomly oriented and measured three times, followed by another three times after 90° rotation. The distance between the top-down acting mechanism and the asparagus spears had to be individually adapted per hand due to varying curvature and diameter of the samples, whereas the bottom-up mechanism struck the spears in the centre at a generally constant distance, as a matter of principle. Based on the good results with microphones in laboratory tests, further tests with these sensors were performed in a demonstrator with a closed circuit. For the bottom-up mechanism, the excitation device was part of the transport carriage, which operated synchronously to the main drive of the conveyor belt. Therefore, the implementation was easy to do (**Figure 3**). In contrast, top-down mechanism required a precise positioning of the lifted asparagus spears (height and horizontal position of the asparagus spear, n = 210) with a fast acting laser scanner (1000 measurements per second). Due to inertia of the excitation, precise positioning and measurement cycle were performed in successive measuring rounds. A controller stored the position data. One measurement cycle consisted of 20 measuring rounds. Ten spears were measured per measurement cycle.

After finishing the nondestructive acoustic measurements, asparagus spears were cut to determine if they were sound or hollow. Spears with more than one percent of volumetric proportion of hollowness were classified as hollow.

The multitude of experimental laboratory setups and the automatic recording of demonstrator data resulted in a large amount of acoustic data (n = 4100 measurements/setup). Therefore, a widely automated data processing was developed based on open source software for numerical computation (Scilab, similar to Matlab [9]). The computer programs included:

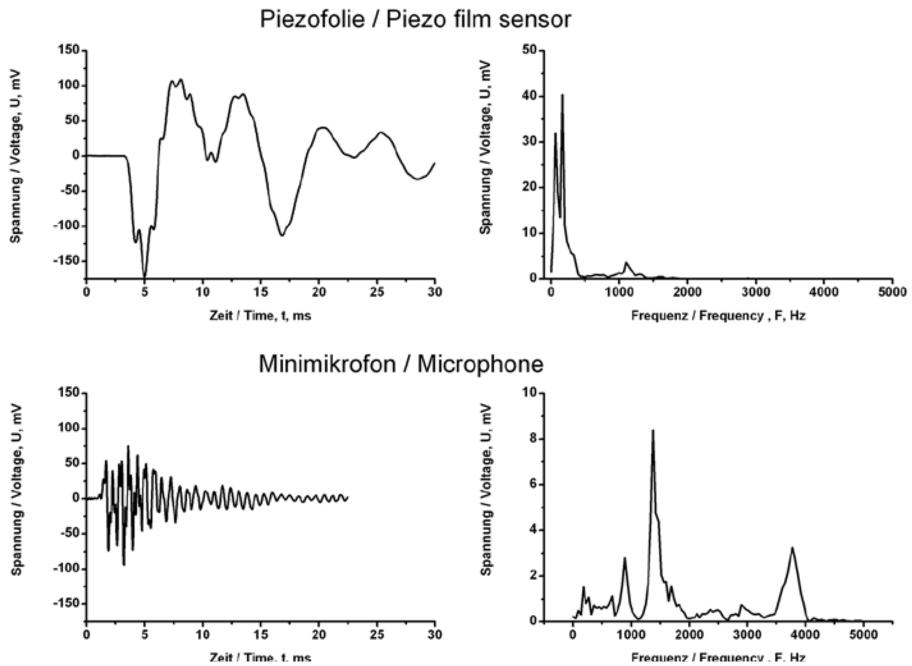
- processing of metadata
- partitioning of recorded measuring signal into frequency sections
- approximation of suitable functions
- tabulating of oscillation parameters
- automatic prioritizing of parameters
- allocation of measurement data to metadata and
- calculation of the predicted hollowness.

Fig. 3



Schematic course of movement of the horizontally and vertically movable transport carriage: (1) Start position, (1) => (2) Measurement device moves diagonally upwards and rises the asparagus spear. (2) => (3) Transport carriage moves synchronous with the main drive of the conveyor belt, measurement is realized. (3) => (4) Supports are retracted by vertical drive. (4) => (1) Starting position

Fig. 4



Typical time- and frequency-domain signal of an asparagus spear for piezo film sensor (up) and microphone (down)

Results

Figure 4 shows a typical oscillation signal in time and frequency domain of piezofilm sensor and microphone. For piezo film sensor maxima with high amplitudes are visible under 500 Hz and a comparably small maximum at 1 000 Hz. By contrast, markedly higher frequencies with relatively high amplitudes were recorded with microphones. This was essential, because test evaluation had been shown that resonance frequencies between 300 Hz and 1 600 Hz correlated most strongly with the attribute “hollow”.

In laboratory experiments, a combination of oscillation parameters enabled a maximum classification accuracy of 77,9 % (piezofilm) up to 83,4 % (microphone). When using two sensors, better results were achieved for the sensor located near the asparagus spear head (**Figure 2**). The higher classification accuracy for microphones could be ascribed to a higher sensitivity of these sensors in the relevant frequency range. Even under praxis-oriented conditions the serviceability of the developed acoustic sensor system was proved. The maximum classification rate was 74,3 % despite of environmental and machine noise.

Conclusion

The newly developed sensor system enables a nondestructive distinction between sound and hollow asparagus spears based on acoustic resonance analysis under laboratory and praxis-oriented conditions. Optimisation of excitation mechanism and signal processing promise improved classification results. Further advancement is expected by evaluating a combination of acoustic data and morphological parameters from image analysis, which is part of the asparagus sorting line, too.

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