Near infrared liquid scanner for detection of explosives at airports

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Introduction

Near infrared (NIR) technology has been applied extensively within the agricultural and food industries.[1] Indeed, NIR technology has great potential for use in many other analytical fields, including pharmacy, cosmetics and petrochemicals. Here we present a new application of NIR for security screening in the form of a bottled liquids scanner for use in airports.[2]

Liquid explosives were used by terrorists in London in 2005. They were carried in polyethylene terephthalate (PET) bottles and were triggered by the flash of a disposable camera. One of the raw materials used was hydrogen peroxide, a readily available grocery item. Since water and hydrogen peroxide have similar physical properties it is difficult to distinguish between the two. There are some methods of detecting hydrogen peroxide such as Raman scattering and ion mobility analysis, but they have limitations when applied at security checks.[3] Some liquids (i.e. coffee) and some coloured bottles produce fluorescence which can obscure a Raman scatter spectrum. In ion mobility analysis, a leak from the bottle or an open bottle is required: passengers may be unwilling to open bottles, particularly bottles to be given as gifts. Therefore, bottles are currently restricted from being brought through airport security. However, some passengers need to carry their own liquids such as special medicine and mother's milk. Duty free items (i.e. whisky and wine) are particularly problematic at international transfer gates because they cannot be carried through subsequent security inspections. In these situations, many passengers have requested that the restriction of carry-on liquids in secure regions of airports, and in aircraft, be relaxed.

Here, a bottle scanner has been developed using NIR technology to help change these restrictions. This scanner can detect hydrogen peroxide in bottles designed for beverages. Visible and near infrared wavelengths between 0.5 and 1 μm are directed through the bottom of a bottle. Light is then collected from the centre of the bottle and the liquid content analysed. The presence of a threat liquid (e.g. gasoline, oil, acid, hydrogen peroxide) is announced by the scanner, with each analysis taking only a few seconds; the scanner can also indicate the concentration of hydrogen peroxide. The bottle scanner could see extensive use at airport security gates and has been tested at Kansai International Airport and Osaka International Airport in Osaka, Japan. Initial results from analysing PET bottles carried by passengers are promising. The scanner is expected to be permanently installed in these airports, allowing passengers to take their own bottles beyond airport security.

Materials and Methods

The bottled liquids scanner uses NIR spectra to distinguish between safe beverages and potentially dangerous liquids. Figure 1 shows a schematic diagram of the scanner. Light from a halogen lamp passes through an IR filter and is carried by two optical fibres. One fibre is directly connected to the spectrometer to check the spectrum of the light source (i.e. a reference), because the spectrum of the halogen lamp changes over time. The other optical fibre is connected to a ring light guide that is attached to the sensor head. Near infrared light is directed from the ring light guide into the bottom of the bottle. Light spreads through the bottle and some light rays are reflected by the wall of the bottle or surface of the liquid and returned to the bottom. Another optical fibre is located at the centre of the sensor head which is just under the centre of the bottle, capturing light rays and guiding them to the spectroscope. The spectroscope has a filter which selects some visible and near infrared wavelengths. Light beams are diffracted by a grating and detected by a linear image sensor (detecting 256 wavelengths from 600 to 1000 nm simultaneously). These data are then sent to a built-in computer to identify the contents of the spectrum, an operation that requires one to a few seconds. The result is indicated by a liquid crystal display (LCD) and an alarm light. The lamp is orange during the measurement, red when a threat liquid is detected, and green if the beverage is safe. Figure 2 shows a photograph of the bottle scanner.

Reference paper as:
Itozaki, H., Shirotan, D., Sato-Akaba, H. and Morimoto, S. (2012). Near infrared liquid scanner for detection of explosives at airports, in: Proceedings of the 15th International Conference on Near Infrared Spectroscopy, Edited by M. Manley, C.M. McGoverin, D.B. Thomas and G. Downey, Cape Town, South Africa, pp. 2-6.

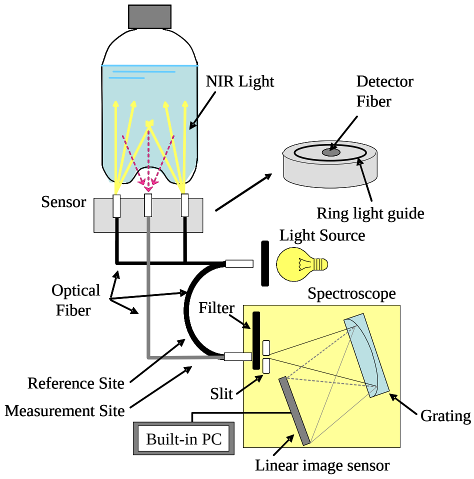

Figure 1. Schematic figure of a NIR bottle scanner.

Figure 2. Photograph of a NIR bottle scanner.

Absorbance spectra of the liquids

The many different liquids carried by passengers require an extensive library of spectra.

Spectra of soft drinks

Figure 3 shows the NIR spectra of some soft drinks distributed in Japan, including mineral water, soda pop, Coke, green tea, black tea, coffee, grapefruit juice, orange juice and a drink with amino acids. Large absorptions attributed to water are observed near 1000 nm (O-H expansion and contraction). Figure 4 shows the second derivative of the absorption in Figure 3 and also clearly indicates NIR absorption by water. The spectral contribution of water was subsequently removed, revealing peaks attributed to the high sugar content of Coke and soda pop (C-H expansion and contraction from C-H_3 and an O-H peak, both from sugar).

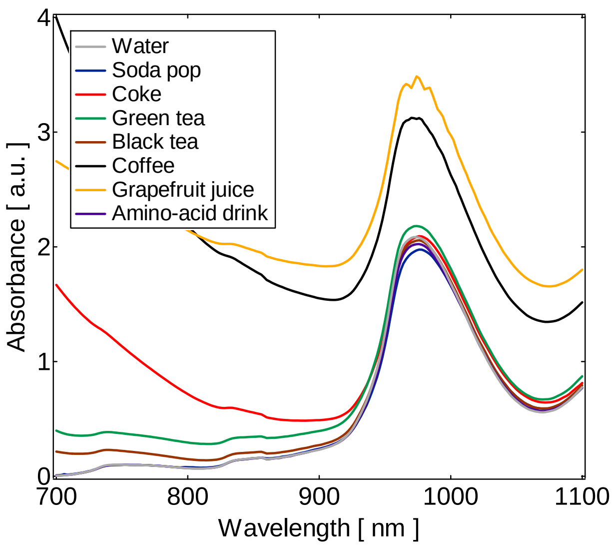

Figure 3. Absorption spectra of soft drinks.

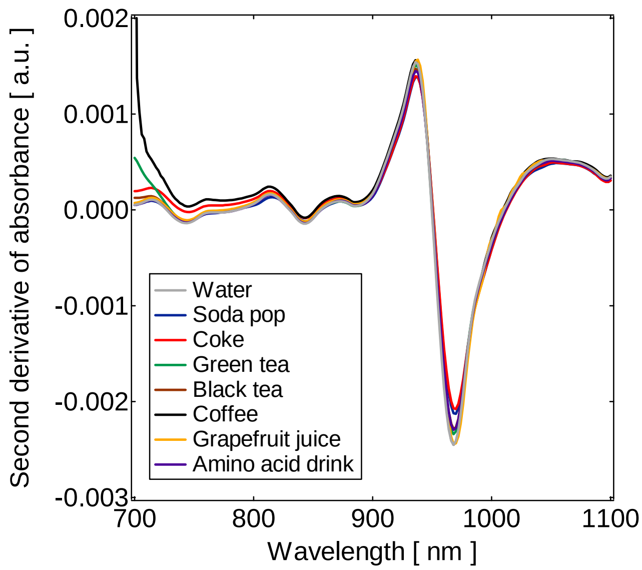

Figure 4. Second derivative absorption spectra of soft drinks.

Spectra of hard drinks

Figure 5 shows the spectra of hard drinks such as red wine, white wine, champagne, liqueur, gin, vodka, and whisky. These spectra also show an absorption peak near 1000 nm due to water. When they are converted to the secondary derivatives in Figure 6, the C-H expansion and contraction of CH_3 in ethanol (908 nm) is readily apparent. Therefore we can distinguish between soft drinks and hard drinks by NIR.

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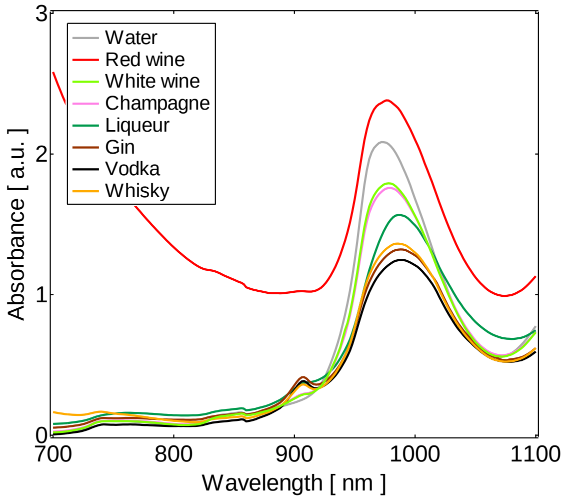

Figure 5. Absorption spectra of hard drinks.

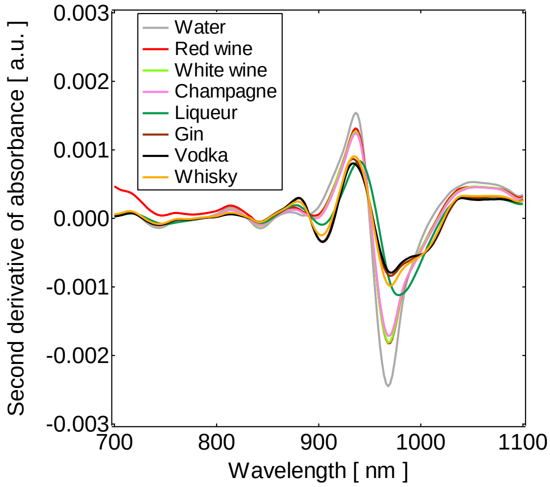

Figure 6. Second derivative absorption spectra of hard drinks.

Spectra of hydrogen peroxide, acid and flammable liquids

Figure 7 shows the absorption spectra of 30% hydrogen peroxide, 30% hydrochloric acid, ethanol, acetone, toluene, gasoline and salad oil; Figure 8 shows their secondary derivative spectra. Peaks attributed to water are observed, as well as some C-H peaks centered around 874 nm and 900 nm. This indicates that these threat liquids can be identified using NIR.

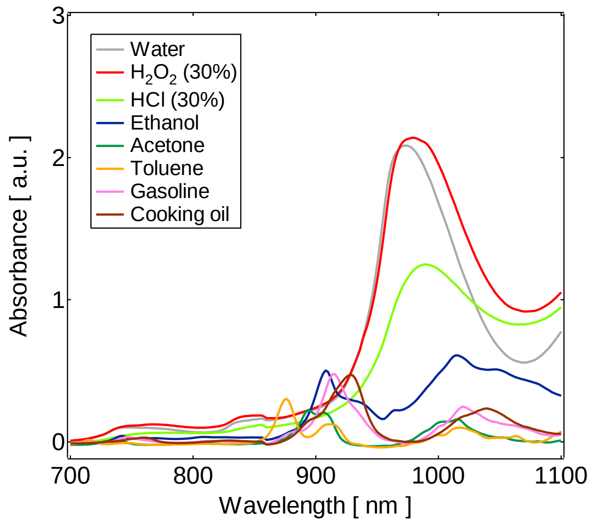

Figure 7. Absorption spectra of 30% hydrogen peroxide, 30% hydrochloric acid, ethanol, acetone, toluene, gasoline and salad oil.

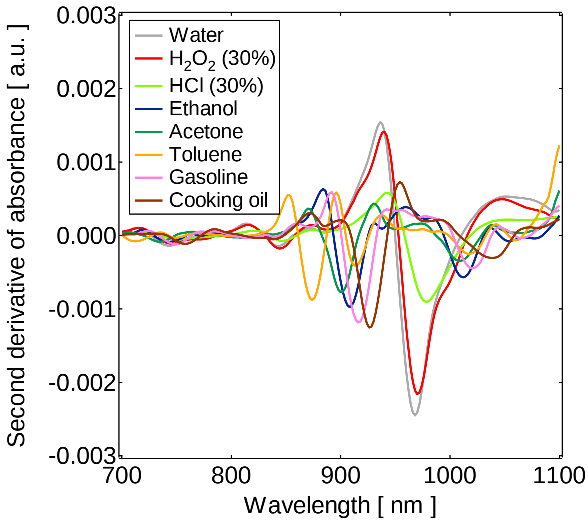

Figure 8. Secondary derivative absorption of 30% hydrogen peroxide, 30% hydrochloric acid, ethanol, acetone, toluene, gasoline and salad oil.

Detection of threat liquids

The principal element method was used to analyse these various kinds of liquid to distinguish threat liquids from safe liquids. Figure 9 shows the distribution of liquids on a map using factor 1 and 2. In this map, only liquids with hydrogen peroxide and soft drinks are located in the negative region of factor 1. Flammable liquids such as gasoline and alcohols are located in the positive region. Samples in the negative region of factor 1 are re-analysed with a partial least squares (PLS) regression model to determine the concentration of hydrogen peroxide. The estimated hydrogen peroxide concentration was accurate to less than one percent error. Therefore the threat liquid with hydrogen peroxide can be detected accurately among various liquids.

Reference paper as:
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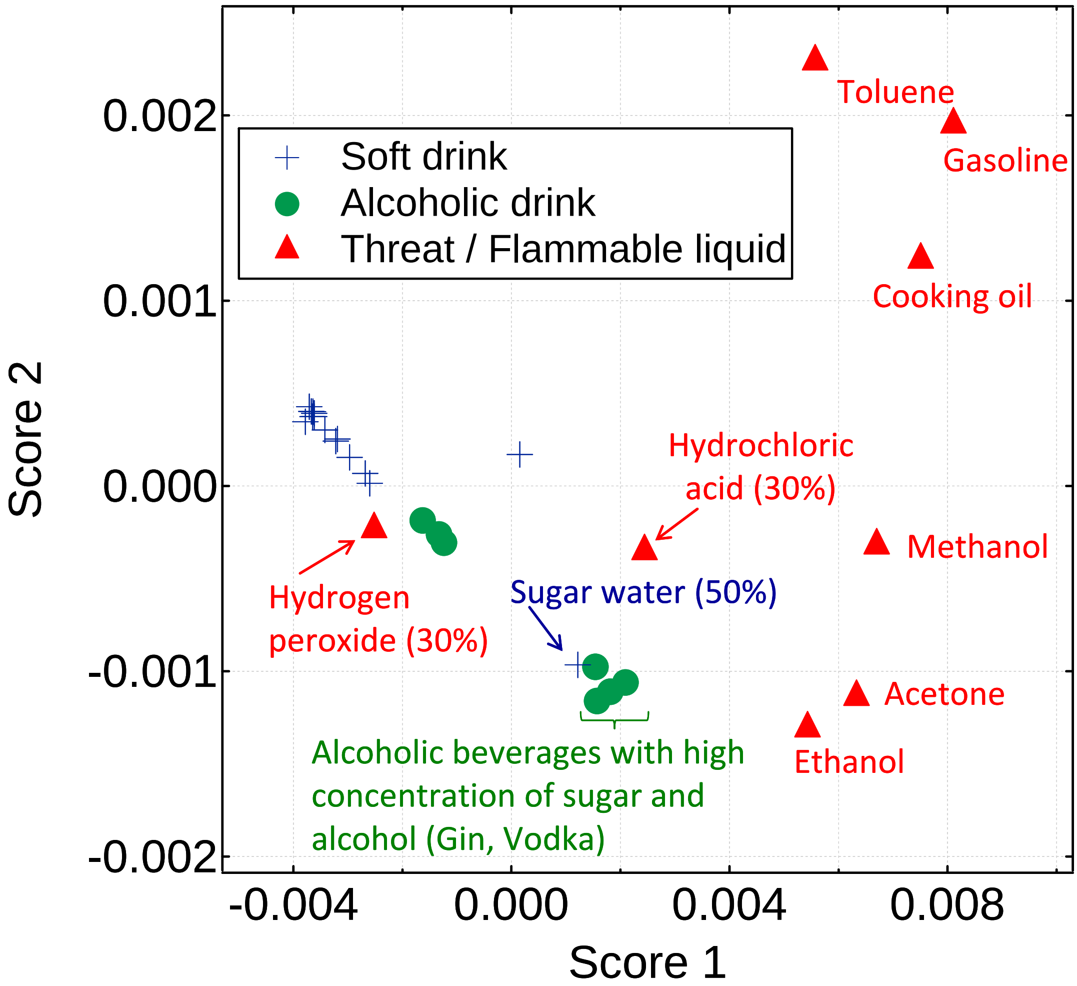

Figure 9. Principal component analyses for separation of flammable liquids, alcohols and soft drinks.

Figure 10. Feasibility test of the bottle scanner in Osaka Int
November 2010.

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Feasibility test in airport

Our bottled liquid scanner was tested at Kansai International Airport in Japan during December 2009 and at Osaka International Airport during November 2010. Figure 10 is a photograph of this test at Osaka International Airport. Bottles (1325) carried by passengers were checked over two days. The liquid bottle scanner worked well and all test samples of hydrogen peroxide were detected instantly. We are planning to carry out a more extensive test to further verify the efficacy of our bottled liquid scanner.

Conclusion

A bottled liquid scanner has been developed using NIR technology. The scanner can detect threat liquids instantly. Hydrogen peroxide, which has been used in terrorist attacks, is distinguished from safe beverages (i.e. water). The scanner has been tested at airports in Japan and has worked well. It is expected that this NIR bottle scanner will be installed soon at security checks at airports and the prohibition of carrying bottles for passengers will be relaxed.

A new application has introduced NIR into the security sector. Our development indicates that NIR technology has the potential to be applied to various fields, much more than we expected.

Acknowledgements

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