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Push-buttons with Material Classification based on Spectral Signatures

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ABSTRACT

In this paper, we introduce an optical sensor system, which is integrated into an industrial push-button. The sensor allows to classify the type of material that is in contact with the button when pressed into different material categories on the basis of the material's so called ”spectral signature”. An approach for a safety sensor system at circular table saws on the same base has been introduced previously on SIAS-2007 /5/. This contactless working sensor is able to distinguish reliably between skin, textiles, leather and various other kinds of materials. A typical application for this intelligent push-button is the use at possibly dangerous machines, whose operating instructions include either the prohibition or the obligation to wear gloves during the work at the machine. An example of machines at which no gloves are allowed are pillar drilling machines, because of the risk of getting caught in the drill chuck and being turned in by the machine. In many cases this causes very serious hand injuries. Depending on the application needs, the sensor system integrated into the push-button can be configured flexibly by software to prevent the operator from accidentally starting a machine with - or without gloves, which can decrease the risk of severe accidents significantly. Another benefit of material-classifying push-buttons is a higher protection against tampering of safety equipment. Especially two-hand controls are incentive to manipulation for easier handling /3/. By equipping both push-buttons of a two-hand control with material classification properties, the user is forced to operate the controls with his bare fingers. That limitation disallows the manipulation of a two-hand control by a simple rodding device.

1 INTRODUCTION

The safe operation of many potentially dangerous machines often requires either the need or the prohibition to wear certain gloves. For instance, a worker who is processing a steel sheet might frequently change the machines and tools he/she needs to cut, roll or drill. The worker must wear strong gloves while cutting and rolling the metal to protect himself/herself, because the metal might have sharp edges. When drilling holes into the metal, the worker must not wear any strong gloves to minimise the risk of getting turned in by the drilling machine. These frequent changes of requirements might easily lead to dangerous situations, where the worker simply forgets to change his/her hand wear. Therefore, the use of a sensor-system at the respective machines checking the required conditions when the machine is started could reduce the risk of accidents. This and other scenarios lead to the idea of integrating a sensor-system for material classification into push-buttons used for machine activation. The presented solution is an active optical sensor-system which classifies the material in contact with the button by sending out radiation in the (invisible) near infrared spectrum with known spectral distribution and measuring the spectral distribution of the reflected share of this radiation. We refer to the combination of specific reflection intensities at the dedicated wavebands as the spectral signature of a material. This is a kind of simplified spectrography. It is to some extent comparable to the human eye, because it uses for example three different channels for the basic ”colour” components, but here they are shifted to the near-infrared spectrum. These spectral signatures in the near-infrared spectrum showed to be typical invariants for many materials. Human skin, for instance, has a unique spectral signature in these wavebands independent from the skin type. This is in contrast to its visual appearance, which depends strongly on the skin tone and is, for example, very similar to the hue of many timbers /6/.

2 OPERATION PRINCIPLE

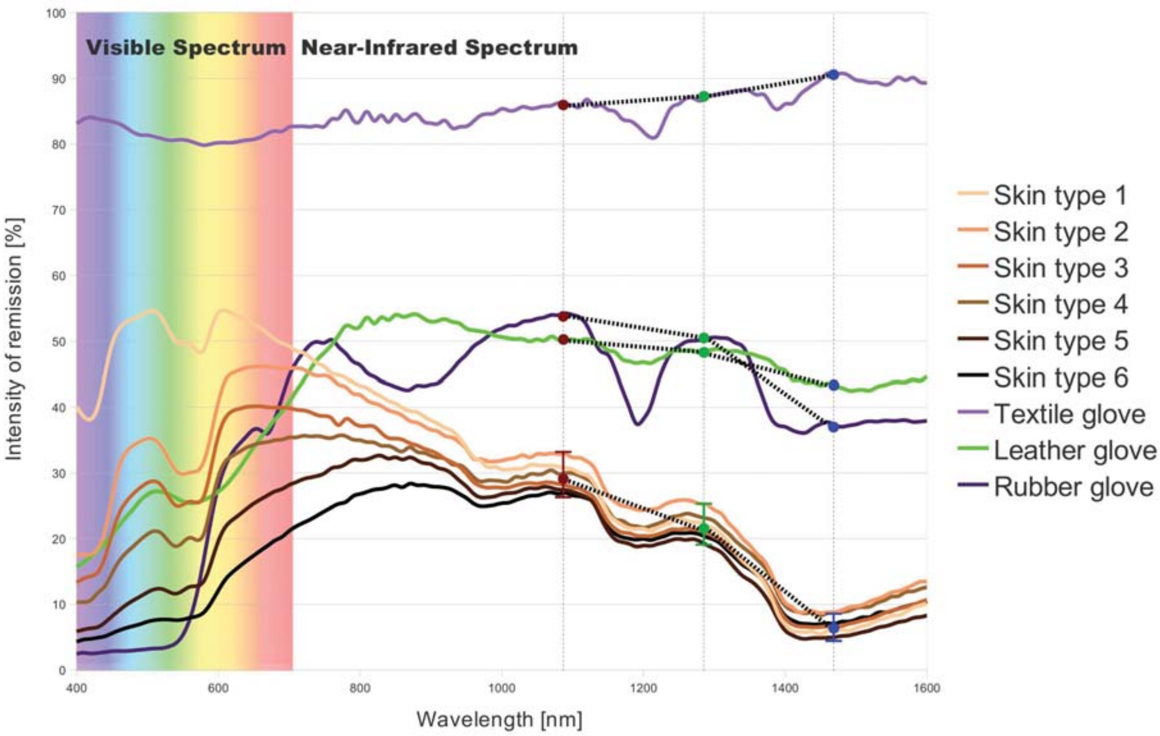

Figure 1: Different skin-types and some samples of gloves at the visible and infrared spectrum

As shown in figure 1, the optical properties of different skin types underlie significant deviations in the visual spectrum. While the visual spectrum is dominated by the concentration of melanin inside the human skin, the near-infrared spectrum is strongly influenced by the high amount of water inside the human tissue. Water has unique features within the near-infrared spectrum due to its high absorption of radiation at about 1,200nm and 1,400nm. These features allow a robust detection of skin against most other relevant materials which contain a lower amount of water by testing the corresponding features at well chosen wavebands within the near-infrared spectrum. These features can be tested by using dedicated LEDs as near-infrared radiation sources. Therefore,

the LEDs must be sequentially activated to illuminate the object in contact with the push-button to acquire the corresponding spectral properties /7/.
LEDs can be pulsed for a few microseconds with high currents. Hence, very short and very intensive pulses of radiation can be generated. An 8-bit microcontroller is used to control the LEDs and to generate a sequence of short radiation-pulses at different wavebands in our design. A photo-diode with a high sensitivity in the near-infrared spectrum is used to measure the radiation reflected by the object of interest. The measured data is read and processed by the same microcontroller. A spectral signature is obtained from the measured data and compared to one or more predefined signatures. If the obtained spectral signature is within specified bounds of the predefined signatures, for example signatures of skin or certain gloves, the command gets approved by the controller. This white-list-approach was chosen to maximise the functional safety of the sensor system by rejecting any unknown signature.

3 REQUIREMENTS

Several requirements for such a safety-related control system are tough and contrary in many ways. Development and production costs must allow a market compliant price for the system. At the same time it needs to fulfil all safety requirements defined by common standards e.g. DIN EN 61496-1 for electro-sensitive protective equipment /4/. Additionally, the system has to reject prohibited hand wear for operation while it must not reduce the availability of the machine. The goal is to design a system that is so fast and reliable that the user will not notice it at all as long as he/she is using the machine with the mandatory hand wear. This implies that a series of measurements and the processing of the data must be completed sufficiently fast. Otherwise, there might be a certain risk that the finger is removed from the button before the measurements are finished. For comparison, very well trained keyboard users type with a speed of about ten key strokes per second, so a single key stroke takes about 100ms. Current prototypes of the sensor-system obtain and process a spectral signature within 300µs. Using ten samples for a more reliable decision leads to a total duration of 3ms, which is about 33 times faster than a fast key stroke.
Mandatory requirements for a push-button at machinery also include shock resistance and electromagnetic compliance. Optical sensor systems must also be sufficiently protected against interfering environmental light. Fortunately, environmental light is mostly screened out by the object in contact with the push-button during a scan operation.
Currently, the material costs for the prototype range about 100 Euro. The custom built Multi-Chip-LEDs are causing 70% of these costs and will decrease significantly when producing larger quantities. Maximising safety and availability may be contrary to minimising costs, but we expect a smart compromise can be found using reliable standard hardware.

4 SENSOR DESIGN

Figure 2 shows one of the first prototypes of the near-infrared skin-detector for common industrial push-buttons. For this set-up a push-button with a semi-transparent cap for integrated signalling lamps was chosen. Only the diffusive glass behind the actual cap had to be removed in order to allow the required precise measurements. The signalling lamp module was simply replaced by the sensor-system. The system is currently triggered by a standard switch-module. Once the trigger rises, the system performs ten measurements for classification. If a programmable number of positive classifications occur, the system sets a digital output signal according to usual CMOS-standards.
The combination of the signal from the standard switch and the logical classification can be used to start a safety-relevant function, as the combined signal cannot be less reliable than the mechanical switch element alone. Furthermore, the hardware of the sensor-system was designed as a category 2 system containing a test-channel. Checking the design using the SISTEMA software showed that it would be suitable for a performance level of 'd' by the means of the DIN EN ISO 13849-1 /2/. Please note that we did not perform an actual certification for any performance level, because the current hardware is a prototype only.

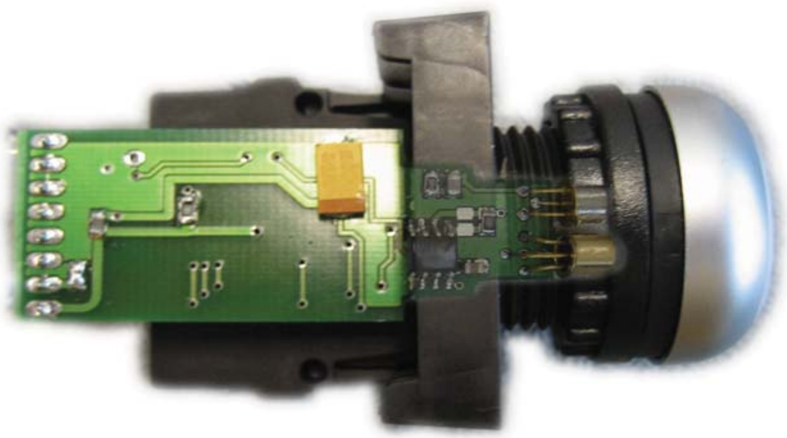

Figure 2: Industrial push-button with integrated near-infrared sensor-system

5 RESULTS

A couple of machines have been equipped with prototypes of the sensor-system. The first machine has been equipped in June 2008. It is a productive machine at a development centre of a car manufacturer. Since then the prototype is tested in daily use and works reliably without any malfunction as we could read in a report the company has sent after one year. The only exception was that they were able to fool the system using a wet cotton glove. Although this is an unusual use-case, the problem should be solved with the successors of the first hardware as the accuracy has been improved.
Two additional drilling machines located at educational institutions of the German employer's liability insurance association for metal have also been equipped with the presented sensor-system and are working without any problems so far.
Another intensive test has been performed during the SPS/IPC/DRIVES 2009 in Nuremberg, Germany, by several hundred visitors. The button was presented on the fair as a joined research project of the Bonn-Rhein-Sieg University of Applied Sciences and K. A. Schmersal Holding GmbH & Co. KG at the Schmersal fair stand. All visitors were accepted by the system using their bare fingers only and no false-positive detection using leather gloves could be provoked. Even fingers covered with very thin transparent plastic foils were rejected in most cases.
As a conclusion, we can claim that the hard- and software of the produced prototypes is working very reliable at distinguishing bare skin and common tear-resistant gloves.

6 OUTLOOK

As an enhancement for the safety of dangerous machinery, the described push-buttons with material classification may be combined with a ”spectral light curtain” at the machinery. This light curtain, consisting of a set of near-infrared sensors similar to the one inside the push-button, can be placed in front of the dangerous parts of the machine, for example in front of the saw blade of a table saw, in order to shut down the machine or to apply suitable safety measures if the operator gets too close to these parts.
Since push-buttons are relevant for functional safety, it is necessary to obey the rules and requirements of appropriate standards. Regarding material-classifying push-buttons, new criteria for their certification need to be defined on top of the given requirements. A central matter is the deviation of spectral properties of human skin from individual to individual. To our knowledge there is no standard defining the spectral properties of human skin and its deviations so far. Statistically significant data of the human skin needs to be obtained to create a basis for the development of a such standard. Therefore, a database of spectroscopic data from the visible to the near-infrared spectrum has been built up. The database currently contains the data of more than 300 individuals. Supplementing information like sex, age, skin type and (in some cases) diseases are recorded as well.
Fortunately, the studies have shown that the maximum deviations of human skin are small enough to allow a clear distinction against common materials of gloves and work pieces like rubber, leather, metals, textiles, wood and plastics. The goal is to acquire necessary knowledge to design and certify a push-button with material-classification on the basis of spectral signatures for the use as a safety-related control system by the means of DIN EN ISO 13849-1 and other applicable standards.

An attractive spin-off of the presented technology is that it allows to develop new designs for zero-force push-buttons. The optical sensors could permanently probe for the presence of a finger to operate the button. Signals from other objects hitting the button by accident would be ignored, as the material classification would be used to approve an operation.

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