Prototype of a Child Safety Driver Assistant System

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ABSTRACT

Farming machinery accidents frequently cause the injury and death of children on farms. These accidents are caused by vehicle blind spots, attached machinery, inadequate security measures, carelessness, and insufficient childcare availability. It is often difficult to separate working and living areas on family farms, making additional security and preventative measures necessary. Farmers are interested in using devices that increase the safety of children in the mechanized working environment.

The system developed to tackle this problem combines two technologies, a wireless radio network sensor and an electrical near field sensor. Detection occurs indirectly, meaning that each child wears a slumbering transponder. Upon entering a risk zone, the transponder begins to communicate with a stationary sensor and alarm unit device mounted on the vehicle.

Initial tests have verified the suitability of these technologies for this universal problem.

To improve usability, it is necessary to miniaturize the transponder, identify detection gaps, and synchronize parallel vehicle use. Danger zones must also be defined in order to create a phased warning system to avoid false alarms, reduce alarm desensitization, and moderate stress for the vehicle operator. A user-friendly design and high service quality would increase the motivation and acceptance of wearing a transponder.

Key words: Child safety, prototype, agricultural machinery, near field sensor, radio sensor network

1. INTRODUCTION

Each year, children worldwide suffer serious injuries and death from being run over by farm machinery. Crushing incidents account for more than half of all accidents involving farming vehicles. Reasons are limited driver vision and insufficient risk awareness by children and parents. The limited field of view is caused by vehicle design and also by nearby objects in the environment. The most dangerous vehicle blind spots are those near the wheels, behind and beside trailer machinery, and directly in front of the tractor bonnet.

Children are curious, act spontaneously, imitate adult activities, and often choose to play in areas near vehicles. It can be difficult for them to perceive the real danger of vehicles and attached machinery.

The most frequent accident situations occur while reversing or during careless manoeuvres in peak work times and stress situations. In these accidents, drivers were unable to detect children early enough to avoid collision. The total stopping distance necessary to avoid a collision is influenced mainly by the moving velocity of the child, vehicle speed, and the reaction time of the driver.

Tractors drive at speeds of 4 to 15 km/h in farmyards and fields, both with and without machinery attached. The legal maximum production velocity for agricultural machines is 25 to 40 km/h. The trend towards designing agricultural vehicles with higher maximum speeds continues to rise. Driver reaction times vary between 0.7 and 1.5 s under normal conditions (Quendler et al., 2006).

Austrian and Bavarian accident analysis reveal two circumstances typical of crushing incidents. In up to 20% of these accidents, the child ran towards a moving vehicle and was subsequently crushed by either the tractor or the attached machinery.

In the second case, in up to 80% of the accidents, a child was hidden in, under, behind, or near the vehicle and hit by the moving vehicle or its attached machines. Children up to six years of age, especially boys, are the highest risk group. Children up to six years old can move as fast as 4.5 m/s, or 16.2 km/h. At this speed, a tractor needs an additional stopping distance of 9.8 m to avoid collision, in a worst case situation.

Accidents do not only result in injuries and death. Other dramatic consequences include the loss of livelihood, long-term disability, and increased risk of illness for accident victims and their relatives. All of these factors have economic impacts.

The separation of working and living areas in order to reduce accident risk is not always possible on family farms in industrialized countries. The reality of the danger can be seen in the amount of farm machinery stock; there are 26.3 million tractors and 4.2 million self-propelling machines in use worldwide. There are 8.88 million tractors and 0.88 million combine harvesters on 9.87 million holdings in 25 EC countries.

For this reason, additional preventive measures are required to reduce the number of crushing accidents. Electronic tools to deliver information about the presence of children in the blind spots surrounding vehicles and their attached machines can be very effective. When the vehicle ignition is turned on, it must immediately begin detecting children within the periphery and if the vehicle is moving, children must be detected over larger distances. This detection can raise awareness and ensure early braking and collision avoidance. The electronic devices should not expose children to electromagnetic radiation. A prototype was developed which causes no continuous radiation exposure and provides a low cost vehicle operator warning system affordable for rural inhabitants (Quendler et al., 2007a).

2. MATERIAL AND METHOD

Based on the above-mentioned requirements, the chosen technique to develop a vehicle operator warning system must ensure child detection in a worst case scenario, guarantee trouble-free operation in an agricultural environment, provide comprehensive protection around agricultural machinery, and lead to a low cost product with high affordability. A combination of electrical near field and sensor network technologies are identified as the most adequate technologies for developing a product best fulfilling the system requirements. The suitability, reliability, and user acceptance of these technologies is determined by field trials and evaluations. Technophile agricultural families tested and evaluated the prototypes. These farm families have a special interest in electronics and live on farms together with children in the jeopardized age group. The tractors in use were medium and large sized with various attached machinery. The testing system consisted of three components: a transponder, a base module with alarm unit, and a near field source.

2.1. Technology choice

The development of a robust direct recognition system for children using video sensors, stereovision, or infrared cameras at all cardinal points around a vehicle is possible but would generate high development and production costs. Video sensors also do not provide direct depth information about relevant objects such as persons, other vehicles, and nearby buildings. Image quality from both colour and black and white cameras suffers from back lighting and insufficient exposure to light.

Radar detection using electromagnetic and electrical waves recognizes objects directly or indirectly. A transponder supports indirect detection and ensures that obstacle detection is not influenced by weather conditions. In a further stage of development, distances could be calculated by measuring the flight time of the electromagnetic waves and the radial relative speed of objects. The measuring of velocity allows tracking and assessment of risks to avoid collision (Viel et al. 2002).

Electrical near field technology was chosen to detect objects immediately surrounding vehicles and machines. Sensor network technology, based on radio waves, was selected for indirect recognition over larger distances.

The electrical near field technology was developed by the MIT Media Laboratory. It was initially used as a means to interconnect body-borne information appliances and electric field sensors for position measurement (Brown et al. 1985). Gershenfeld (1995) realized the possibility of transmitting data by modulation.

The principle of electronic communication in the immediate vicinity of agricultural vehicles and machinery is based upon the fact that all electricity conductors (metal) produce an electromagnetic field near the ground. The electric “aura” of the transmitter takes all parts of the tractor and possible attached machinery into account, leaving no “dead” areas. The “aura”

of the human body communicates via the transponder with the base sensor on the vehicle (Quendler et al., 2006).
Radio sensor networks are used successfully in industrial automation. The sensor network is able to cope with distances of up to 50 meters. Multiple transponders can operate on separate vehicles simultaneously, each one using an unambiguous identification number. One of the most important advantages of sensor nodes is their low power consumption requirement (Intanagonwiwat 2000). Disadvantages of radio technology are their dependency upon the direction of ultra short waves and certain shading and reflection effects, which can lead to detection gaps in the immediate surroundings of vehicles. Therefore, these gaps need to be closed by an electrical near field not reliant upon sight contact with a detection distance of up to 2.5 meters.

2.2. Prototyping

The prototype combines hardware and software. The hardware device consists of three modules: a base unit, a transponder module, and a near field source. The transceiver chip is low in price, uses little energy, allows data transfer and simple communication with the microcontroller, and operates on 433 MHz bandwidth. The near field source uses a 13.56 MHz frequency and communicates wirelessly with the base device.
The base module has a liquid crystal display (LCD), a 7-segment-display, light emitting diodes (LEDs), pushbuttons, an acoustic alarm device, and RS-232 and RS-485 interfaces. The LCD and Serial Peripheral Interface Bus (SPI), chosen for their clear display of data, operate on a 3.3 V supply voltage. A piezoelectric sound generator emits acoustic alarm signals up to an intensity of 83 dB. The main components of the basis module are the microcontroller, the radio chip, and the circuit board with a chip antenna.
The near field source, a separate unit, operates on a 3 V CR2032 coin cell battery. It must be installed on the tractor with the 13.56 MHz signalling device mounted properly on the chassis to achieve a stable scattering field without detection gaps.
The electronic circuit of the transponder is also powered by a CR2032 coin cell battery and includes the relevant radio hardware for communication with the base module. It consists of a near and far field detection circuit. A transistor circuit, driven by a microcontroller, functions as an activation switch for the near field detection circuit, which is powered separately by a 9-V battery block. Most of the time, the transponder is in sleep mode, meaning that the more energy-consuming near field detection circuit is turned off and only the energy-saving far field detection system is in operation. If the far field transponder detects a vehicle or if a vehicle ignition is started, the near field sensor is activated. The size of the prototype transceiver at the current stage of development is 13 x 6 x 3 cm.
For simultaneous multiple usage of the 433 MHz frequency, a time division multiple access (TDMA) mechanism is used. The base module sends out a data batch and waits for the transponder module reply. This procedure is done on an infinite loop. Transmitting conflicts for up to four multiple transponders are avoided by the clear channel assessment function of the transceiver.
The software is programmed for one basis module and the detection of up to four persons. The program process of the transponder starts after initialisation of the "wake-on-radio" function of the radio chip. The calculated time of notification is 144.2 ms. The near field sensor and microcontroller are deactivated if no tractor is detected during a selected period of time (t_{sleep}).

The hardware components are reactivated by the “wake-on-radio” function. Once the near field status is updated, a data batch is transmitted.

The program cycle of the base module begins with the initialization and monitoring of the personal devices, which supply the far and near field status. Then the Liquid crystal displays LCDs are actualized, the alarm device is switched on and off, and the data packages with the tractor identification number and transponder module address are posted. The reception mode is enacted for a specified time and is followed by the short transmission of a data batch to the transponders. If there is no detection within the time t_{sleep}, the liquid crystal backlights are deactivated. If a transponder is detected, the passive cycle is interrupted and transponder data, ID number, and near field status are evaluated. After the transponder flags are updated, the interrupt cycle is terminated and the main program cycle is activated.

A visual indicator on the LCD provides near and far field identification. The detection of a child in the near field is expressed by “x” on the line “n” and in the far field by “x” on the line “f”. The 7-segment-displays show the ID number of the detected device after receiving detection information from the transponder.

The acoustic alarm is a periodical beeping signal. The far field alarm starts with long breaks between signal tones. The audio warning of the near field is characterized by a higher repetition frequency and a louder tone, expressing acute danger.

The prototype consists of three components, a base module with alarm unit, a transponder, and a near field source. The base module was mounted within the direct field of vision, on the heated side cab window or in front of the steering wheel.

The near field source is mounted flexibly to determine the optimal coupling positions for avoiding detection gaps. The transponder is carried by a person and informs the driver about its presence in a danger zone.

Picture 1: Base module, transponder, and near field source

2.3. Usability Assessment

In order to identify the advantages and disadvantages of the two prototypes, usability assessments were conducted over several months. The test subjects operate large-scale farms in Lower Austria and Styria. They live together with children on farms and also continuously receive visits from neighbouring children. During the testing phase, various work processes such as transport, cultivation, tilling, and harvesting were performed in farmyards and on fields. There was different farm machinery in use. The different test situations were documented on evaluation sheets, each situation on a single sheet; the farmers were trained in filling out. They had to record the testing conditions and identified detection quality (very good, good, bad and worst) of the near and far field sensors. Questions on the evaluation sheet were climatic situation, material and consistency of the driving ground, material and characteristics of obstacles and related detection quality, montage position and usability of base module with alarm unit, near field source and transponder. At the end of each testing period, three times over the testing phases, the farmers were interviewed to these key aspects and their stated impressions were recorded in writing. Critical, difficult understandable situations were simulated with the farmers on their farms and metrologically verified for ensuring of reliable data for further development, especially about non-transparent unfavourable detection distances and gaps.

3. RESULTS AND DISCUSSIONS

Test results are available for far and near field detection dimensions and distances, the installation position of the near field source, indication instruments in the driving cab, and transponder design.

The far field shows diffusion and shading characteristics common to radio detection. Detection distances of between 40 and 50 meters were achieved outdoors. Shorter distances were measured in the farmyard, near buildings.

Insufficient near field distances were assessed around equipment with too little metal mass in the outer areas. The distances varied between a few centimetres and 2.5 meters. Optimal installation positions for the near field source were identified for various machinery combinations. The optimum 360 degree detection radius around tractors and attached machines is obtainable from a near field source with a line section positioned in front or at the rear of the vehicle, in the centre of the metal tractor frame. An expansion of the detection distance can be attained by coupling into the board electrical system. This can be combined with the machinery-related adoption of sending power in order to close gaps around attached equipment with insufficient massive parts. This function requires an additional power outlet, supplementary and serial to the branch circuit.

From the farmer's point of view, an acute warning for distances of 5 to 7 meters is needed in farmyards in order to stop in time and to avoid too many false alarms. An extension of the near field is not possible; it can only be used for the detection of persons immediately near the vehicle. An alternative solution is the further development of the far field, the integration of propagation time measurement, and the definition of risk zones. Multiple, variable detection distances and information about the distance to the jeopardized person, related to the usual driving speeds in farm yards, can reduce the rate of false alarms.

The current far field warning signal makes pauses that are too long and the tones are too quiet during certain work processes. The sound volume should be adaptable to the noise level of work processes and have varying appeal grades. Additionally, pleasant tones are adequate for the broader risk zones but shrill tones should be used for the immediate surrounding of the vehicle and its attached machines.

Shrill tones indicate the existence of a life endangering situation and should incite the driver to an immediate response. The tone of the far field can be loud yet pleasant to avoid an angering effect, response reduction, or even a shut-off, caused especially by too many false alarms.

From the farmer's point of view, the acoustic signals are the most important warning mechanism. Helpful visual information could be lights or displays about the distance between the jeopardized person and the machinery.

The transponder has an inconvenient size and design, it must be miniaturized and provide a higher degree of usability to children. Important for improved detection, both in terms of reliability and distance, is the direct contact to the skin surface and the alignment of the transponder antenna to the vehicle. Direct contact could be ensured, for example, by a wristband with a sturdy fastener to prevent inadvertent loss. Farming families who accommodate guest children on holiday recommend the addition of a warning signal to alert the child when he or she enters a risk zone.

The achievement of a high level of safety requires the continuous wearing of a transponder by each child. Factors which could influence the acceptance and motivation of wearing the device are design, colour, and name.

According to the testers, a safety system should contain one base module and at least two or three transponders. Recommended extra services are the possibility to buy additional transponders as well as the availability of different designs. The recommended price for a sales unit is up to 300 EUR, and up to 20 EUR for a single transponder (Quendler et al., 2007).

In the case that the sales price of the serial product is high, it should be possible to easily transfer it to other vehicles. It could then also be used for seasonal machinery and increase willingness to equip farming vehicles with a costly safety system.

4. CONCLUSIONS

Incidents of children being run over by machinery on farms occur because of inadequate security measures, carelessness, overwork, and insufficient childcare availability. In many accident situations, children run towards moving vehicles or hide in, under, behind, or near a starting vehicle. To avoid this type of accident, children must be detected by electronic devices both in the immediate vicinity of active machinery and across large distances. The combination of a wireless sensor network and an electrical near field detection system was chosen to develop an electronic device to cope with these circumstances and reliably recognize children at low cost. Detection is indirect, meaning that children must wear a transponder.

The prototype system consists of a slumbering transponder, a base module with alarm unit, and a near field source. The communication frequency bands are 433 MHz in the far field and 13.56 MHz in the near field. The base module uses an LC and a piezoelectric sound generator to indicate danger situations within the specified zone. The transistor circuit, which is driven by a microcontroller, switches the near field sensor on and off. The software is programmed to recognize up to four persons and one base module. The clear channel assessment function of the transceiver is used to avoid conflicts. The near field source must be mounted on the tractor chassis. The base module is positioned in the driver's cab.

Prototypes were tested by two farmers for several months to evaluate security improvement and usability. The far field sensor had a range of up to 40 m, leading to increased false alarms which were partially reduced by the farm yard shading effects caused by buildings and other

vehicles. Integrating run time measurements and risk zone definition could eliminate this weakness. Risk zones could provide stepped situation information according to the degree of risk.
The detection range of the near field sensor varied according to the mounting position of the near field source and type of machine attached. The near field sensor is influenced by machinery shape and extent of metal component content. The detection distances across a 360° radius varied from a few centimetres up to 2.5 m.
The breaks between far field warning signal tones were too long, and the signals for both near and far fields were not audible enough during loud work processes. Louder yet pleasant tones are recommended for the far field. Shrill, insistent tones expressing the importance of immediate action should be used for the near field. The current transponder is carried by a person and must be reduced in size and the design improved to achieve higher wearing comfort. Transponder attachment should be simple and the design could be adapted to sex and age to attain a high degree of identification by children.
The next steps in development are to eliminate the weaknesses mentioned above and to identify possible security gaps by testing a prototype series in a multitude of farming environments and work situations.

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