An Early Warning Device for Identification of Tractor Accidents, Rapid Alert and Assistance

Sarghini F., D'Urso G.
DIIAT – University of Naples Federico II
Via Università 100 -80055 Portici (NA) ITALY
Tel: +39 081 2539457
e-mail: fabrizio.sarghini@unina.it

Abstract
Although today's tractors are safer then before, they are still involved in many farm accidents. Statistics show that most machinery-related accidents occur due to human negligence, due to errors involving improper or lack of machinery maintenance, taking shortcuts to save time, failure to follow safety rules, failure to read the operator's manual or ignoring machine's warnings.
While a lot of effort in researches has been devoted to the optimization of protective devices (ROPS-Roll Over Protection Structures), little attention has been devoted to post-accident medical assistance.
In particular, statistically, in fatalities or in serious injuries accidents is frequently found a condition in which the driver is prevented in making requests for immediate help, being immobilized as a consequence of rollover crushing or due to the impact of the tractor with trees or with the ground. In these cases time in alerting a rescue team is a key factor in saving operator's life. In this work a combined rapid alert device is presented, developed integrating a GPS-GSM chip with a MEMS (Micro Electro-Mechanical Systems) tilt sensor, including miniaturized accelerometers and inclinometers in order to detect rollovers and collisions in real time.

Keywords: rollover, safety, gps

Introduction

Accidents due to of agricultural vehicles such as tractors represent a primary cause of death or serious injury in agriculture.
The Roll-Over Protective Structure (ROPS) was developed to protect tractor operators from death and disability from these events by providing a protective zone for the operator in during a tractor overturn. ROPS are most effective when used in conjunction with a seatbelt, which keeps the tractor operator inside the protective zone during an overturn. Nonetheless, a lot of fatal accident still happen.
In particular the dynamics of the incidents historically presents critical points in timing and in the mechanisms of rescue.
Indeed, it is often verified by the fact that the person incident was not able to report the incident as trapped beneath the overturned vehicle, and also that access for emergency vehicles to the accident site has been further complicated by the missing reporting of the access paths to the place itself.

<u>Tractor's accidents statistics</u>

Tractor overturns are the leading cause of occupational agricultural deaths.

In Italy data about tractor accidents are dramatic: a statistic (with approximated defective data, because obtained by collecting data on newspapers and unrelated different sources) published by ASAPS (ASAPS, 2010)- Ossevatorio "Il Centauro" during the period May 2009-May 2010, reported 296 accidents, including 174 fatalities involving 140 drivers, and 174 seriously injured persons.
Among the reported accidents, 199 cases (67%) are referred to off-road operations, especially in wood and fruit related agricultural operations.
In the United States, between 1992 and 2005, 1,412 workers on farms died from tractor overturns (NASS, 2008).

Type of injuries in agricultural tractor accidents: going beyond ROPS

In 1965 Rees published on the British Medical Journal an interesting analysis of agricultural tractor accidents, analyzing 14 fatal and severe injuries cases. Three of them were fatal, in four of them he noticed the presence of fracture of pelvis, in two the fracture of spine, and in other four cases the operator was found pinned beneath the tractor. In one fatal case, Rees wrote *"A 67-year-old married farmer was found dead in his farmyard. He was lying beneath an overturned tractor. The metal seat of the vehicle had pressed upon and crushed his chest. He had died from multiple injuries to the thorax. No one witnessed the accident."*
Although the large amount of studies devoted to improve safety of agricultural off-road operations and tractor stability and the technological advances, a large number of tractors related accidents still happen nowadays.
Analyzing Rees' study we could underline the following key-points:

1) in most of tractor's accidents, operators are locked beneath the tractor;
2) severe injuries involving fractures of pelvis or spine are often present;
3) accidents happen often without any witness and as a consequence medical care could not be provided promptly.

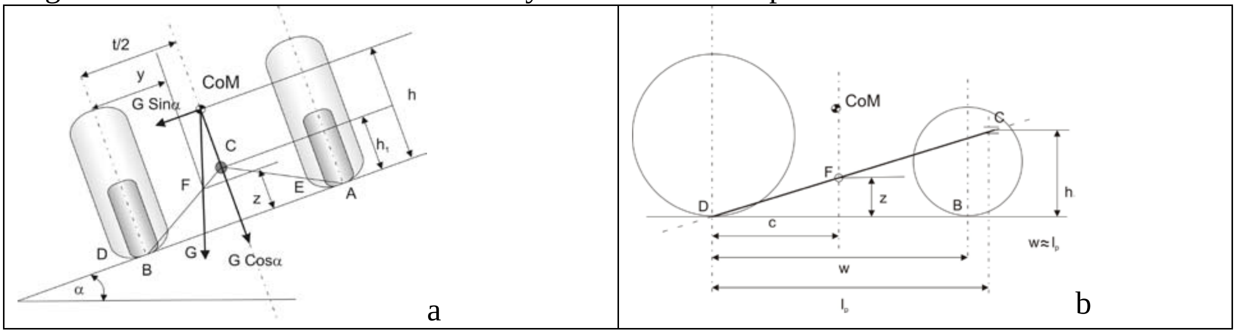
Once the accident happens, a key point to save human lives relies in the possibility to provide a fast medical care, which means fast accident detection warning, precise geographical localization and fast and appropriate medical care.
In order to find an effective solution to the points highlighted by Rees analysis, we decided to develop an early warning device using "on the shelf" components and industrially available technology.

Materials and methods

Lateral rollover angle

As the purpose of this work was to develop a device for early warning in case of accidents, our interest was focused in the detection of accidents, and rollover angle was chosen as a warning parameter.
The static lateral stability criteria are determined using classic rollover theory, developed by Coombes (1968) and other workers in the late 1960's, and later completed by Chisholm (1979a, 1979b, 1979c).

The limit of stability is reached when the resultant force of all the forces acting on a vehicle reaches the boundary of the stability plane, providing that the wheels have not started to slide along the contact surface.
Figure 1a and 1b can be useful to shortly remind the concepts.



The stability plane for a vehicle with a pivoting axle is described by an inclined triangle: the apex of the triangle is the (front) axle pivot point; the triangle base being a line connecting the ground contact points of the wheels on the non-pivoting axle (rear wheels). The sides of the triangle join the ends of the base line to the (front) axle pivot point. A typical inclined triangular plane is shown in the schematic Figures 1, joining points C, E and D.
Figures 1a and 1b show the front and side views of a vehicle which is about to roll-over laterally.
The vehicle body will rotate about points of support at the rear wheel contact D and front axle pivot pin C. At instability the support force at the third corner of the stability plane, i.e. the rear wheel contact E, will be reduced to zero. The resultant force, G (due to the vehicle weight) is about to pass outside the stability plane intersecting the boundary line DC at point F.
The slope angle (α), at which lateral roll-over of a pivoted-axle vehicle commences, defines the first of two stages of instability. At this angle all weight comes off the upper wheel on the non-pivoting axle. However, as the vehicle body continues to roll around line DC, a point will occur, on most vehicles, when the travel limit of the pivoting axle is reached. At this point roll will occur about a line joining the base of the lower front and rear tyres (points D and B in Figures 1). This is the point or angle β, that depicts the second stage of stability. For simple 4-wheel rigid frame vehicles, only the second stage instability angle applies, due to the absence of a front axle pivot. Referring to Figures 1, it can be deduced that the second stage instability slope angle β (not shown) is given by Equation (4):
Different considerations are required if we consider light tractors (mass <= 600 kg) or heavy tractors (mass > 600 kg).
In the first case, Scarlett et al, 2006 reported a general classification and experimental data about first and second instability angle in case of static and dynamic conditions.
Following consideration and classification of the small vehicle types available on the market , they found that within each group a significative number of vehicle variants are present and that there were some vehicles types which lay on the borderline between groupings. In order to classify the vehicles, consideration was given to the basic vehicle physical characteristics: namely the number and position of the wheels; which axle was steered (front or rear); the possible incorporation and location of an axle lateral pivot; the approximate weight distribution between axles (often indicated by the operator seating position); and whether the mass and mass distribution of the vehicle changed during operation (e.g. by collection of cuttings).

Three general configuration were defined:

1) configuration A: 4-wheel, rigid chassis, non-pivoting axle or independent suspension;
2) configuration B: 3-wheel ,forward-facing ,single front wheel or 4-wheel with pivoting front axle;
3) configuration C: 3-wheel ,rearward-facing , single rear wheel or 4-wheel with pivoting rear axle.

In their work, the first instability angle ranged from a minimum of 30.3° (30.5° in dynamic conditions) to a maximum of 46° (45.2° in dynamic conditions).
For heavier vehicles, we followed the work of Guzzomi et al, with data pertaining to 102 narrow-track tractors fitted with front ROPS, with masses in the range 780–2380 kg used to calculate COG and rollover theoretical angle.
The data was used to theoretically calculate, from geometry, the angle required to cause 'lateral' rollover. In the latter, it was assumed that there was no deformation (tyres/surface, etc.) and no front axle pivot, hence rollover occurs at the angle when the COG exits the base defined by the tyres.
Experimental data showed a theoretical angle ranging approximately from 36° to 50° , where the first data refers to tractors with a mass higher then 2500 kg and a COG over 0.8 m.

Hardware platform

Previous application of GPS technology in tractor rollover problems was mainly focused in increasing off-road vehicle stability mapping integrating GPS/GIS and video technology (Liu et al 1999). In the aforementioned paper a site-specific driving safety management and stability
mapping system was developed utilizing a measuring system of tractor stability, Differential Global Positioning System (DGPS) and Geographic Information System (GIS) and Video Mapping System (VMS). In our case we are interested in developing a fast hardware platform, able to transmit essential information about the accident in short time, avoiding possible black out due to platform failure as a consequence of the accident itself.
Several handheld device or smartphones today incorporates tilting sensors and a GPS chipset.
Nonetheless their GPS fix is often poor, and tilt sensors do not provide the necessary reliability, time resolution and vibration filtering.
For this reason we decided to assemble high quality sensors already used in critical applications.
Two platform were developed: a high computational power platform based on a 100 MIPS processor interfaced with a MEMS integrated tilting sensor, and a low cost platform with self assembled sensors a a reduced computational power.
In this paper we will focus on the first one.
The purpose of the hardware platform is the following:
1)to determine the dynamics of rollover;
2)localize geographically the location of the accident through a GPS tracking system;
3)communicate data to central control base the accident by phone SMS message to immediately activate the medical care rescue.

In order to fulfil the mentioned task, the hardware was composed by

1) a microcontroller board, the "thinking" brain of the system. Compared to a programmable logic system, a microprocessor system allows greater flexibility and expansion of functions;

the motherboard is a FOX LS832, based on Axis 100 MIPS processor, 32 MB RAM, 8 MB Flash (which hosts the file system), Ethernet interface, two USB Host ports, three UART interface for Secure Digital cards and three RS232 interfaces. This card uses Linux operating system, thus allowing rapid application development.

2) a three-axis tilt sensor for the detection of three-dimensional positioning of the vehicle; we used U.S. Digital X3M Multi-Axis Absolute MEMS Inclinometer (US Digital, 2009), which is a digital three-axis high precision MEMS tilt sensor.
The sensor X3M is an absolute inclinometer using MEMS technology (micro-electro mechanical systems), and allows the detection angles on 360 ° of extension. The X3M sensor is a very flexible device, allowing the user to connect via the serial interface RS232, across six programmable outputs or through both. The X3M sensor can also be configured to operate as a precision tilt switch to 1 or 2 axes.
The sensor calculates the angle of tilt (tilt) sensing acceleration from MEMS accelerometers embedded in a monolithic integrated circuit, since the acceleration of gravity, centrifugal forces, and speed changes are all forms of linear acceleration Configurations and parameters are stored in non-volatile memory, and the sensor is interfaced to the microcontroller board via a serial port.
The sensor can use only two axis simultaneously, in our case roll and pitch axes.

3) A GPS / GSM board for the localization of the vehicle and the transmission of alarm messages; we used a Telit GM862-GPS chip connected to the microcontroller via a serial port embedded in a specially purpose designed carrier board.
The GM862 module has a quad-band dialer GSM / GPRS modem functionality with an integrated 20-channel GPS receiver based on the high-sensitivity SiRFstarIII ™ single-chip. The GPS receiver features low power consumption has a resolution of the position with precision of less than 2.5m, SBAS (WAAS and EGNOS) as well as high sensitivity for indoor fixes.
The hardware interconnection is shown in Figure 2, while the assembled prototype in shown in Figure 3a and 3b.

Figure 2 – Hardware connections

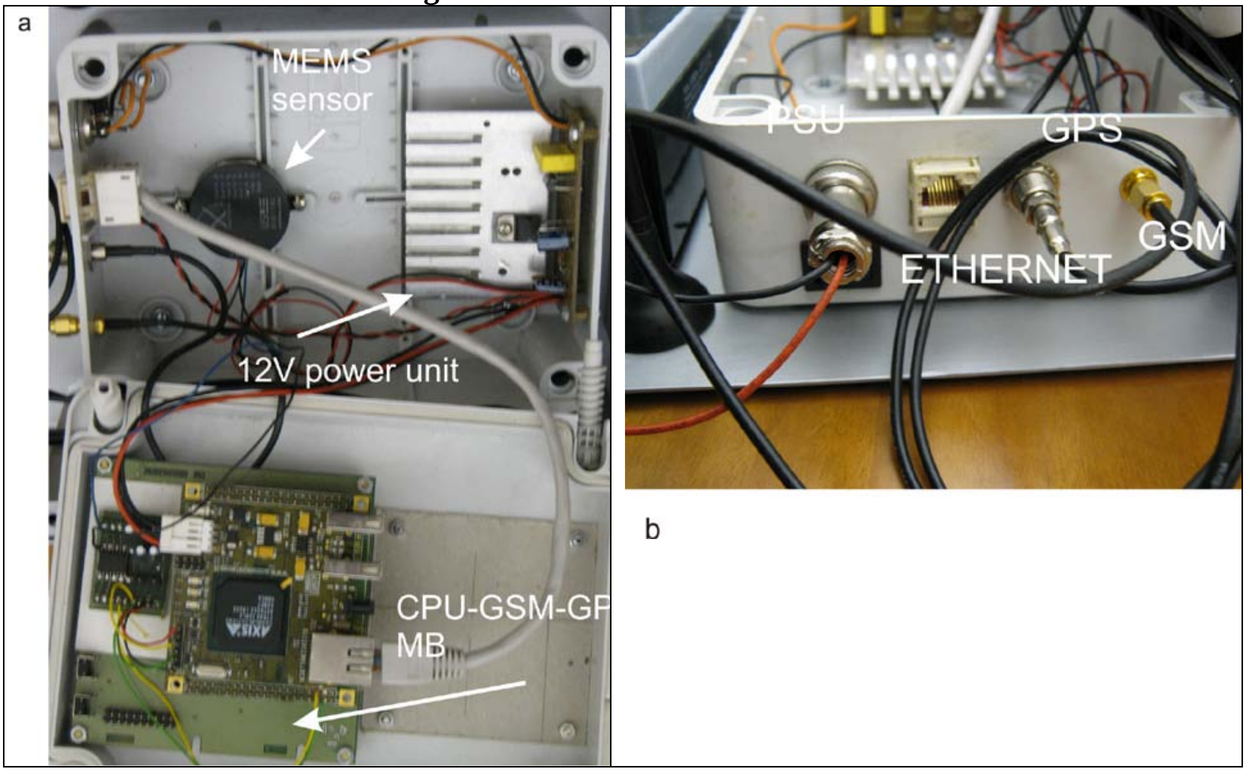


Figure 3 – Assembled prototype

Results

<u>Sensor validation and setup</u>

The X3 sensor uses a FIR (Finite Impulse Response) digital filter to provide electronic damping of the angle readings, and the response has a triangular weighting that decays linearly to zero.
The damping time is user programmable from 2 milliseconds to 5000 milliseconds: the higher the damping time, the lower the effects of local spurious acceleration.

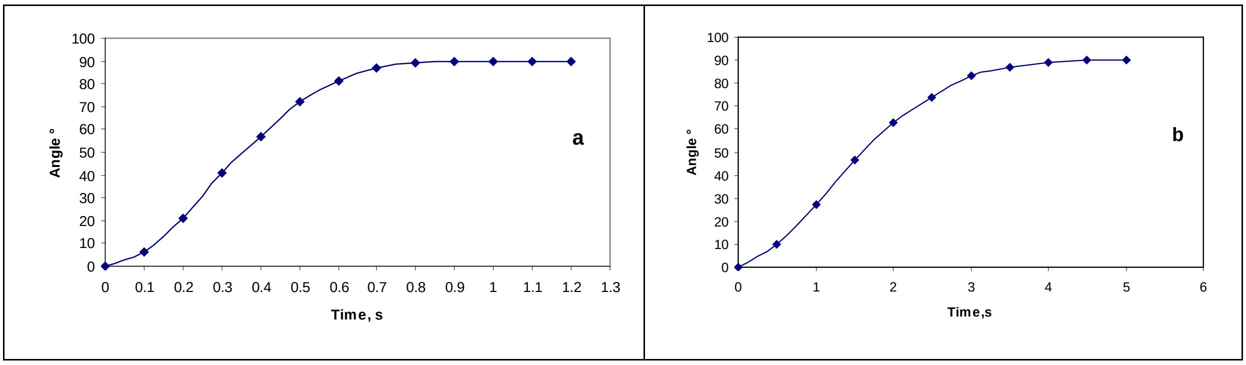


Figure 4: effect of dumping time of 1s and 5s filtering width on sensor response for a 90° step change

Effect of dumping time are shown in figure 4a and 4b, reporting the X3's angular output with a 90 degree step change in position for 1 second and 5 second damping times In fact, increasing the damping time will average more samples together in order to form the reported angle: this will reduce noise in the output but increase the response time.

A laboratory test was performed on a continuous artificial rollover for 360° with an angular velocity from 1 rad/s to 3 rad/s , which is the usual range in case of lateral rollover (Sillelia et al, 2007), in order to setup the appropriate filtering window time , and the value was set to 50 ms; results are shown in Figure 5a (200 ms) and b (50 ms).

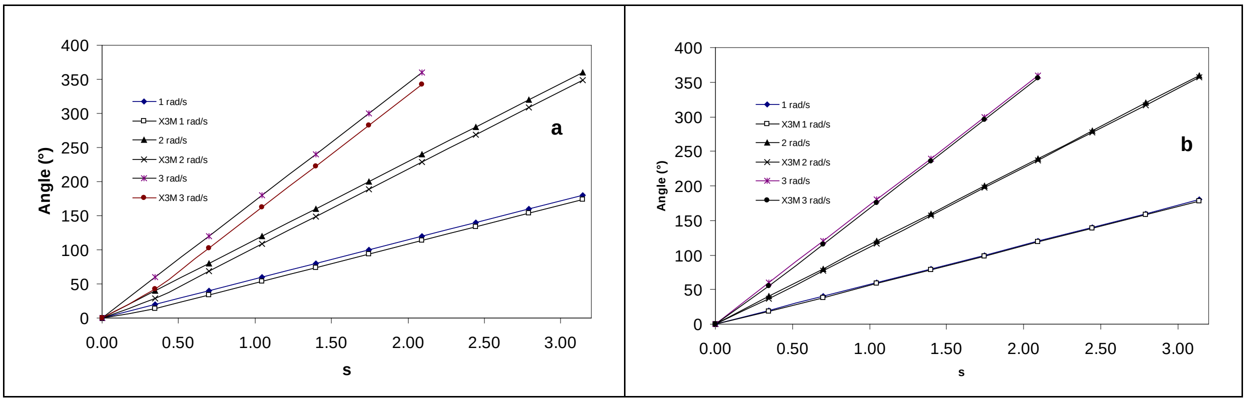


Figure 5 Effect of dumping time on a 360° constant speed rollover: 200ms (a) and 50ms(b)

<u>Software platform</u>

The software platform, written in C, was designed to detect an initial lateral rollover, and to report the operator the incipient danger with an acoustic alarm.
It can work as a data logger of the inclination and position of the vehicle for the analysis of rollover dynamics, and in case the vehicle overturns or in case of shock due to a frontal impact, it sends an SMS to one or more phone number including an alert message, including NMEA GPS coordinates.
A server with a GSM receiver is then able to import GPS data into Google Earth software.
In the future experimental campaign a GIS database including access road to local sites will be linked to NMEA data.

Conclusion

The proposed hardware system represents a simple and low cost solution to reduce the number of fatal accidents in agricultural operations involving tractors and to provide a fast and appropriate medical rescue in case of accidents, further reducing the effects of injuries.
At the moment a major test project is under development, focused on a wide test on 100 vehicles operating in different terrain conditions; and advanced version of the hardware platform is under development, providing a better interface (a touch LCD screen), more computational power, and an improved 9 DOF inertial measurement system at a lower cost.

References

Associazione Sostenitori e Amici della Polizia Stradale, http://www.asaps.it

A J Scarlett, J N Reed, D A Semple P C Seward, A D Stockton & J S Price, 2006, Operator roll-over protection on small vehicles, Silsoe Research Institute report no. 432 for the Health and Safety Executive 2006

Chisholm, C.J. (1979a) A Mathematical Model of Tractor Overturning and Impact Behaviour. Journal of Agricultural Engineering Research (24), 375-394. Silsoe, UK.

Chisholm, C.J. (1979b) Experimental Validation of a Tractor Overturning Simulation. Journal of Agricultural Engineering Research (24), 395-415. Silsoe, UK.

Chisholm, C.J. (1979c) The Effect of Parameter Variation on Tractor Overturning and Impact Behaviour. Journal of Agricultural Engineering Research (24), 417-440. Silsoe, UK.

Coombes, G.B. (1968) Slope stability of Tractors. Farm Machine Design Engineering, September 1968, pp.18-33.

Guzzomi A.L., Rondelli V., Guarnieri A., Molari G., Molari P.G., Available energy during the rollover of narrow-track wheeled agricultural tractors, , Biosystem Engineering, 2009, 104, pp. 318 – 323

Liu, J., P. D. Ayers and M. Vance. 1999. Off-road vehicle stability mapping integrating. GPS/GIS and video technology. ASAE Paper No. 99-7047

National Agricultural Statistics Service. [2008]. 2006 farm and ranch safety survey. Report No. Sp Cr 3-1 (1-08). Washington, DC: U.S. Department of Agriculture, National Agricultural Statistics Service.

Silleli H., Dayıoglu M.A., Gultekinb A., Ekmekcic K.,. Yıldız M.A, Akay E., Saranlı G., Anchor mechanism to increase the operator clearance zone on narrow-track wheeled agricultural tractors: Prototype and first tests, Biosystem Engineering, 97 (2007), pp 153 – 161.

Telit SpA ,http://www.telit.co.it

U.S. Digital, http://www.usdigital.com