**Safety operation of autonomous agricultural vehicles in vineyards and orchards**

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*Abstract:*

The problem of field operations safety for agricultural vehicles has never been more important with new autonomous agricultural systems coming into the fields. Both low-tech end and high-tech end solutions of today's approaches have its solutions on the market. Low-tech solutions rarely provide protection across the profile of the vehicle. Obstacle detective technologies like LiDAR or ultrasonic transmitters struggle with the wider span of anomalies found in agriculture settings.

The novel approach of PeK Automotive's Slopehelper Autonomous Agriculture Vehicle combines simplicity, reliability, and serviceability. The safety bars that are connected directly to the braking system of the vehicle will initiate the vehicle's brake drums immediately and without any additional hardware, software, or control devices in case of a mechanical contact with an obstacle. Low forces reaction mechanism, together with machine safety design programs produced by the International Standards Association (ISO) add to the outstanding functionality and reliability of the Slopehelper's safety bumpers system.

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Vehicles driving around without a human behind the wheel were once the work of pure science fiction, but thanks to modern vehicle tech companies such as Tesla Motors, this fiction is slowly becoming reality. While the public eye focuses on these so-called autonomous passenger vehicles, a similar revolution is quietly occurring out in the world's farmlands. Autonomous agricultural vehicles have been rising in both popularity and necessity, and a new generation of technology entrepreneurs such as Slovenia's PeK Automotive (PeK) are tackling the challenge head-on. PeK's Slopehelper Autonomous Vehicle is the leading market option for wineries, orchards, and similar row crops looking to automate field operations, reduce labor, and achieve true 24/7 equipment availability. In this article, we'll take a deep dive into Slopehelper's safety systems, how these systems fundamentally differ from the competition, and how PeK's philosophy of simplification sets it apart in this otherwise overly-complex high tech space.

**Autonomous Agriculture Equipment: A Challenge for Safety**

In recent years, interest in automating agricultural work has grown immensely. Across the 20th century, efficiency gains in the food industry largely occurred at processing and distribution levels, whereas agricultural development was centered around biology and chemistry, a la fertilizers and genetic plant engineering. The mindset here was that food only grew at one speed, but once it was harvested, the downstream markets would be the places to gain throughput. Today, food demand is greater than ever, a fact that pushes the need for automation down to the farm layer as well. Now, the industrial food sector is developing autonomous farm vehicle solutions in parallel with passenger vehicles, benefiting from much the same technology. It's quite interesting to think that the same type of algorithms and machine-learning tech that navigate a Tesla electric car from home to work, may also navigate farm equipment to pull acres of crops from the earth.

One particular challenge in both the Tesla and the farm vehicle examples is that of ensuring safety. Allowing several thousand-pound metal equipment to roam around without a human driver is a risk unto itself. To then place that rolling behemoth in off-road conditions on open land, with any number of potential hazards and swiftly changing conditions, requires even more precaution.

Most farm vehicle manufacturers on the market today approach these safety concerns in one of two ways: either they employ low-tech solutions that offer marginal protection on the basis of low cost, or they utilize very expensive, overlapping layers of technology on the basis of market differentiation.

On the low-tech end of the spectrum, several equipment manufacturers rely on impact sensors positioned adjacent to each tire. These sensors only protect from impacts directly in front or behind the tire. No protection is provided across the profile of the vehicle itself. There would be no response or indication if the vehicle were to strike a person or object anywhere other than at the tire. Further, such small-scale bumper solutions tend to require stiff mounting brackets, and are constructed of overly rigid materials in order to take exposure to tire debris. This makes these bumpers difficult to activate, and therefore not completely reliable.

On the high-tech end, equipment manufacturers typically turn to costly imaging and reflective sensors such as LiDAR or ultrasonic transmitters. Using light or sound waves, these sensors measure the transit time of the emitted waves in order to approximate the presence and distance of obstructions. While these sensors are popular and accurate in passenger vehicle applications, they can struggle with the wider span of anomalies found in agriculture settings. They are also expensive, require multiple overlapping sensors to cover the vehicle's path, require frequent calibration, and require high computational and electrical power to operate.

Beyond the shortcomings of the above detection technologies, there are also limitations in the upstream control and response components in most of today's available designs. To properly protect personnel and property from damage that can be caused by an autonomous agriculture vehicle, the response time from the moment of hazard detection all the way through bringing the vehicle to a complete halt must be nearly instantaneous. Such fast response times are difficult to design, difficult to maintain, and even more difficult to guarantee.

**Slopehelper's Premiere Safety Platform**

PeK Automotive's Slopehelper Autonomous Agriculture Vehicle takes a novel approach to addressing the challenges of today's vineyards and orchards. We believe that safety should be approached simply, such that higher complexity often leads to lower reliability in the long run. Whether it be through lack of maintenance, failure of sensitive components, calibration drift, or software errors, the risk of failure grows as the system's complexity grows.

Slopehelper's safety design is simple, reliable, and serviceable by any competent farm mechanic. There is no need for special tooling, technology training, or costly frequent part replacement. Let's first take a look at the design philosophy behind our solution, and then onto specifics of how our safety system works.

Everything about Slopehelper is built around the concept of modular, simple, reliable solutions that any agricultural owner can access. In this spirit, the design of our safety system began with tapping into existing regulations that would allow us to create a standardized, internationally-recognized solution.

At the foundation of our design, we turned to the European Machine Design Directive 2006/42/EU. This directive states that automotive applications should be designed with ready-made, commonly available, commodity components. Brake pads, wheel bearings, electrical relays, fuses – all parts of the system should be regular, everyday parts that operators in any country, at any technology level, can obtain. This standard also infers that mechanical and electrical technicians familiar with modern vehicle systems should be able to provide service without advanced or specialized expertise. This foundation allows Slopehelper's vehicle platform to be universally plain and intuitive to users across the globe.

**High-Tech Safety Begins with Everyday Simplicity**

We centered our safety system around the singular objective of bringing the vehicle to an immediate halt should any hazard be encountered. To do so, the Slopehelper uses a robust yet straightforward braking system controlled directly and physically by safety bars positioned around the vehicle. Our safety bars are designed around two principles:

- The bars extend the full width of the vehicle, and are installed front and back, positioned to contact any obstruction in front of or behind the vehicle. Additional safety bars are installed on

any trailer attachments, such that there is always a safety bar at the leading and trailing edge of the vehicle.
- The safety bars directly connect to the Slopehelper's braking system. When a safety bar contacts an obstruction, the bar will pivot and pull on a braking cable, which will engage the vehicle's brake drums immediately and without any additional hardware, software, or control devices involved. This allows the fastest, most reliable braking reaction possible.

The Slopehelper safety bar system is incredibly simple, direct acting, and comprised of standard vehicle components found in most local auto supply shops. To see a video of the safety bar in action on the Slopehelper YouTube channel, please click here: https://www.youtube.com/watch?v=xX5h6XIwBIQ

The safety bars are installed using low-force positioning hinges, where contact with small, odd-shaped, or moving objects will still engage the braking system. The safety bar mechanism reacts to forces as low as 5 lbs. / 22.2 newtons – this value derived from public building safety standards governing emergency escape exits.

Further, safety bars are positioned a half-meter away from the vehicle, such that a bar can contact an obstacle, fold down gently enough to engage the brake system, and bring the vehicle to a complete stop all before the vehicle body nears the obstruction in front of it. This distance is calculated as a function of the reaction time and braking distance of the vehicle. We fully considered the Slopehelper's weight, speed, and surface friction variables in these calculations. We even included allowances for poor weather and ground conditions, as well as grade inclines in both uphill and downhill travel directions. We have successfully tested and achieved immediate vehicle halts in mud, frost, hard and soft soils, gravel, concrete, asphalt, bare earth, tall grass, and even standing water.

Our safety bar hinge mechanism provides even further safety benefits inherent to its design. The hinge allows for the safety bar to collapse when encountering an obstruction from any direction, and at any angle.

It's worth noting that the above direct braking system also applies to the Slopehelper's top equipment deck, locking fluid totes, equipment, or materials in place should any of the safety crash bars be activated.

The mechanical design of our safety bar system accomplishes most of the functionality needed to protect personnel and property, but we did not stop there. In looking at potential false-start or free drift situations, we wanted to add a layer of protection that would offer the same level of immediate and instant protection even during a full power loss, or motion generated by an external force. To achieve this protection, we implemented a 'normally-engaged' control layer on top of the braking system. This control layer is largely mechanical, consisting again of standard vehicle and control components, and simple in design.

Slopehelper's normally-engaged braking layer consists of the following features:

- The brake drums are held closed with a spring-loaded brake cable at all times. This brake cable is direct-acting on the brake drums, and is the same cable used by the safety crash bars.
- To overcome the spring-loaded cable and release the brakes, a pneumatic actuator is used to push on a cable lever, removing the closing force on the brake drums and allowing the vehicle to move. This only occurs when the control program directs the vehicle to travel.
- There are multiple pneumatic actuators across the vehicle, all of which are energized by multiple pneumatic compressors and routing solenoid valves within the vehicle.
- In short, if electric or pneumatic power are lost anywhere in the vehicle, the brakes immediately engage as the mechanical spring and lever revert to their default static closed position. This reaction is independent of any automated programming sent from the vehicle's controller, as it occurs at the mechanical layer directly within the braking system.

In situations where power might be lost within the vehicle, this normally-engaged braking system will stop the vehicle in its tracks. More so, if the vehicle is struck by another moving object, it will not move

since its brakes are fully engaged by default. (Slopehelper does include a temporary free-clutch override for towing).

**Assuring High Availability through Safety Redundancy**

All of the above safety technology in the Slopehelper occurs at the mechanical level, with direct-acting safety bars, normally-engaged brakes, and calculated braking distances based on vehicle mass and speed. That said, we felt that there was still room to improve safety!

The next design challenge was to ensure that all of these safety devices were completely reliable, and that we built fault tolerance into the design from the mechanical layer and above. To gain inspiration, we turned to standard machine safety design programs produced by the International Standards Association (ISO).

EN ISO 13849-1 is an international standard covering machine design safety controls. This body of code prescribes a probabilistic approach to safety control system engineering, emphasizing proactive examination of risk potential and the design of safeguards targeting those risks. In short, our ISO-compliant control strategy is founded on thorough risk assessment of the Slopehelper in operation, where we find personnel, equipment, crop, building, animal, and other vehicles to present particular hazards that the vehicle must avoid. Due to this very wide variety of potential risks, we arrived at the conclusion that our safety system must have 100% availability, and have a long service life. We addressed these objectives in two ways:

- To assure system availability and reliability, we integrated a redundancy layer into our design. Using a 1oo2 ("one out of two") approach, we duplicated each critical component throughout the safety system such that if any one part were to fail, the redundant backup would still be in effect.
- Selecting components with long MTTFs (mean time to failure), and requiring maintenance and replacement intervals well under these MTTF limits, we can be confident that the probability of simultaneous failures is virtually zero.

Even still, should two components in the redundant system fail, we can turn again to the normally-engaged braking system described above that would activate in this case.

Last but not least, what about a safety situation where a nearby operator needs to stop the vehicle immediately prior to impact with a safety bar? Around the perimeter of the vehicle and on all accessory trailers / equipment, emergency stop pushbutton stations are installed for manual activation by an operator. The emergency stop stations are large red and yellow buttons that can be pushed by hand, resulting in the same reaction as if a crash bar were to have been engaged. The E-Stop buttons are electrically wired through the pneumatic compressors that defeat the normally-engaged mechanical braking cable – pressing any E-Stop button will instantly cut power to the pneumatic defeater, which will in turn pull the brake cable closed by spring force as described above.

As we can see, the Slopehelper's safety scheme is multi-faceted, incredibly reliable, redundant, and simple. Founded on recognized international standards and based on regularly available commodity parts, our design is the definitive example of a modern agricultural vehicle safety architecture which we hope inspires not only our customers, but the broader autonomous equipment industry as well.

For more information on the Slopehelper Autonomous Agriculture Vehicle, please visit https://slopehelper.com/, see our demonstration videos here: https://www.youtube.com/channel/UC_mTr6LbT9ETGGoN8e8_5Pw, or contact PeK Automotive Slovenia at info@pekauto.com, +386-307-77-050.

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