Autonomous self-propelled units: what is ready today and to come in the near future

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CNH

1 Review of enabling technologies

There are certain technologies available today and in many cases have been around for more than 20 years that are true “enablers” or cornerstones that make a remotely controlled or autonomous vehicle much easier to develop. Technologies like high precision GPS based hands free guidance systems, vision systems, a higher level of computational power on vehicle control modules, telematics and standardized communication protocol for on-board vehicle bus and vehicle to implement bus communication and control. What follows is a short discussion of the commercially available enablers mentioned above with references sited or web links to more detailed information.

The paper will end with several examples of autonomous vehicles available today and to come in the near future.

For the United States one of the key enablers however is not strictly tied to technology but more so linked to resent legislative acts like the bill signed on the 25th of September 2012 by California’s Governor Brown approving autonomous vehicles on select California roads, joining Florida and Nevada as States that are starting to address autonomous vehicles in public places. The current discussions around a draft safety standard (Highly Automated Agricultural Machines (HAAM)) by the European Union (EU) ISO/TC23 body will also be a major step toward the acceptance and rules of acceptance for highly automated agricultural vehicles.

1.1 Guidance systems (GPS based)

There are two primary satellite based global positioning systems available today and a third with several satellites launched. In Dr Shearer’s paper *Trends in the Automation of Agricultural Field Machinery* presented at the 2011 Club of Bologna meeting there is an excellent description of the primary satellite constellations; the US Global Positioning System (GPS) currently with 30 health satellites, Russia’s Global Navigational Satellite System (GLONASS) currently with 24 satellites and GALILEO, a satellite based positioning system currently being implemented by the EU for civilian applications. Two more of the planned 30 satellites were launched on the 12th of Oct 2012 taking the total constellation to four.

All of the major agricultural equipment manufactures a long with a number of short line manufactures and numerous aftermarket suppliers take advantage of the GPS and/or the GLONASS satellite consolations to provide multiple levels of precise location knowledge and steering control to their customers. The following information discusses the position accuracy for commercial applications related to three of the Case IH family of GPS receivers tied to steering systems and in many ways is very similar to other OEMs offerings. Additional information is available on caseih.com and also at the other OEM web sites.

1.2 Differential GPS (DGPS) with WAAS orOmniSTAR correction

A vehicle with a GPS antenna receives GPS signals from the GPS satellite constellation. The Wide Area Augmentation System (WAAS) and OmniSTAR® services have many GPS receivers at known reference locations that send a correction messages to control stations, which then uplink the correction message to a geostationary satellite (WAAS or OmniSTAR). The geostationary satellite then sends the correction message to the DGPS antenna on the vehicle, which applies the correction factor.

1.3 WAAS

6 - 8-in. (15 - 20-cm) pass-to-pass accuracy with sub-meter repeatable accuracy < 1 min convergence.
WAAS was developed by the Federal Aviation Administration to augment the GPS with the goal of improving its accuracy, integrity and availability. The WAAS correction is available to all at no charge where available in North America.

1.4 OmniSTAR HP

- 2 - 4-in. (5 -10-cm) pass-to-pass accuracy with 4-in. (10-cm) repeatable accuracy < 40 min convergence OmniSTAR® HP is best suited for:
- High-performance broadacre seeding, planting spraying and harvesting applications Operations in areas with open views of the sky at all times

OmniSTAR HP is a more accurate correction solution. Like OmniSTAR XP service, it is a L1/L2 solution requiring a dual-frequency receiver. Data from OmniSTAR's network of reference sites is utilized together with atmospheric corrections.

It operates in real time and without the need for local base stations or telemetry links.

1.5 RTK

is a highly precise technique that results in one-inch, year-to-year accuracy. It requires two specialized GPS receivers and two radios. One GPS receiver is set up as a base station within an 8 mile (12 kilometer) radius of the field you are working so it can send the correction message to the roving receiver. Both receivers collect extra data from the GPS satellites, known as an L2 Band that enables better precision. There is an unlimited number of users, so it is ideal for large farms and fleet users

1.6 CenterPoint RTK

< 1-in. (2.4-cm) pass-to-pass accuracy with < 1-in. (2.4-cm) repeatable accuracy < 1 min convergence. CenterPoint RTK is best suited for:

- Farms within 8 miles of an established RTK base station or base station network;
- Farms without line-of-sight obstructions such as hilly terrain or an abundance of trees;
- Use with row crops, strip tilling, land leveling and drainage applications in which the best horizontal and vertical accuracy is required

1.7 Vision systems

In the 2010 Club of Bologna meeting Dr Jens Moller presented a paper Computer vision – A versatile *technology in automation of agriculture machinery* where he focused on two specific applications for smart vision systems; weed control and auto-guidance of tractors and self-propelled machines. For the most part Dr Moller discussed two dimensional vision systems (2D, with a single lens) with the weed control section of his paper and three dimensional vision systems (3D, with two lenses) for the machine control portion. The 3D stereo systems discussed are able to provide distance information not available in a 2D system by known geometric positions of the two lenses verse the different viewpoints of a unique image captured at the same moment by the two lenses. Features in the two images captured at the same moment have an offset which is a function of the distance to the feature. The offset can be calculated by finding the same image features in both images.

With a smart 3D stereo vision based control system like CLAAS' AutoFill that automatically controls the spout position of a forage harvester an operator can focus on harvesting tasks other than watching a forage wagon being filled as an example and is also another enabler or cornerstone on the path to autonomous vehicles. Trying to replace the humans ability in a task like filling a silage wagon requires a vision system that can capture an image and also distance information, or as with human eyesight, depth perception.

There is another smart 3D vision system available today that was not discussed in Dr Moller's paper and deserves some discussion as it will also play a role in replacing the human ability of depth perception in some machine based control applications.

New Holland has just launched a unique forage spout guidance system called IntelliFill which is based on a 3D camera where images can be obtained with depth. The single infrared sensor/camera captures the light reflected back, obtains a perfect picture of the trailer filling by making 4 scans every 20 milliseconds. The 3D scene-sensing technology is based on the time-of-flight principle in the frequency domain which allows the system (and therefore the operator) to have full functionality in the dark and dusty conditions that can occur during harvest as well as bright day light.

The 3D camera is mounted on the spout and can measure the distance to the four corners of the wagon and the filling degree inside the silage wagon. Through this information, the turning angle of the spout and the position of the deflector in the end of the spout is automatically controlled. As a result, the filling of the silage wagons is done completely and automatically.

1.8 Higher on board computational powered control modules

An embedded system is a computer system designed to perform a specific task. It is "embedded" as part of a complete device including mechanical, electrical, hydraulic, etc. parts and is often required to operate in real-time. Embedded systems normally have micro-controllers with digital signal processing (DSP) as the processor. Due to the fact that embedded systems are designed to perform specific tasks they are typically optimized for performance, reliability, cost and geometric size. The first micro-controllers for embedded systems were developed in the early 1970's. The first commercially available micro-controller was the TMS 1000 released by Texas Instruments in 1974. The Intel 8048 was released for embedded control applications in 1977. At this time microcontrollers used PROM program memory (programmable only once) or EPROM (erasable program memory via exposure to ultra-violet light).

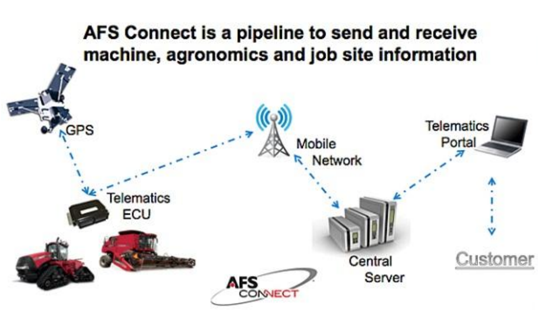
Embedded systems and microcontrollers have developed in complexity and capabilities at a rate similar to the computer industry. 32-bit microcontrollers with floating point capability are readily available at present. Despite this about 50% of all CPU's sold in 2006 were still simple 8-

bit microcontrollers (according to data from Semico). The reason for this is that many simple systems don't require high levels of computational power (e.g. clocks, washing machines, etc.).

The agricultural machinery industry has very closely followed the automotive industry in the development of onboard electronics and control systems. This is primarily due to the fact that the auto industry provides volume and economies of scale that provide the best performance to cost ratios. In the late 1970's New Holland started research into including embedded control systems on their equipment. In the early 1980's New Holland released round balers and large square balers that used embedded microcontrollers. On round balers it was used to control the wrapping and bale shape systems and on large square balers it was used to control the density system. In the mid-1990's New Holland released the Genesis 8970 tractors that had 16-bit fixed point microcontrollers and an industry first 29-bit CAN bus for communication between multiple embedded controllers. Today agricultural machinery can have 15 or more embedded controllers of different performance levels onboard (display/monitor, GPS Antenna, Guidance controller, powertrain controller(s), TECU ISOBUS controller, HVAC controller, Radio, etc.). At present the display typically utilizes a 32-bit floating point processor for image processing and guidance path planning. Powertrain controllers often utilizes 16-bit fixed point or 16-bit floating point microcontrollers. These levels of processing power allow for relatively complex calculations to be performed onboard in real-time, another enabler of autonomous vehicles.

1.9 Telematics & vehicle to vehicle communication

Having a gateway open to the agricultural machinery's onboard communication bus from remote locations via telematics is one of the cornerstones for remote control of a vehicle and the vehicles functional settings. Like the previously mentioned enablers most of the major OEMs and a number of aftermarket suppliers have just recently introduced telematics systems that open the door to more than the current remote diagnostics and monitoring. A short discussion of a few commercially available telematics systems follows.



Case IH **AFS Connect™** is the blending of a global positioning system, computers and wireless telecommunications technologies that allow agricultural businesses and OEM manufacturers to send near real time machine, agronomic and job site information to and from connected machines.

In June 2012 John Deere introduced their "**John Deere Remote Display Access**" which allows a farm manager or a dealer, with the owner's permission, the ability to view the in-cab display and provide remote support. From an Internet-connected laptop, smart phone or similar device anyone with the "John Deere Remote Display Access" can view the operator's Greenstar™ 3 2630 display screen. With the Remote Display Access someone remotely linked and able to see the vehicle display screen on their PC can help identify a problem or recommend machine settings and walk the vehicle operator through the steps needed to resolve many issue particularly around vehicle control settings. Further information can be found on the John Deere website (http://www.deere.com/wps/dcom/en_US/industry/agriculture/our_offerings/feature/2012/remote_display_access.page)

Like Case IH AFS Connect™ and the "John Deere Remote Display Access" both AGCO and New Holland have telematic systems with similar capabilities. The new **AGCOMMAND telemetry system** from AGCO provides near real time access, via a cellular modem and computer, to most of the machine data which can help a manager improve operations and profitability as does **New Holland's PLM™ Connect**.

2. Discussion of functional automation/control – ready today

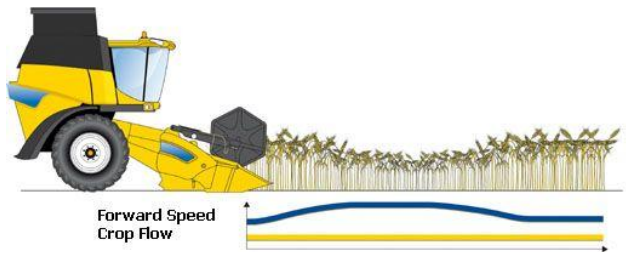
One of the challenges with a totally autonomous vehicle is the required manual adjustments needed to optimize field operations of agricultural equipment. As an example the varying of ground speed to maintain crop loading of the threshing system on a combine or the tuning of the fan speeds and concave openings to have clean grain samples without sacrificing grain loss. Having smart crop sensing and automatic system controls are one of the requirements needed as we look at the more complex ag equipment that could be made into autonomous vehicles.

2.1 Feedrate control

New Holland, Claas and John Deere all have a control system that helps maximize the combines harvesting efficiency and increases the combines average productivity by automatically adjusting ground speed to maintain a constant load on the combine, or maintaining a constant speed or controlling grain loss on a preselected target. The automatic control systems on a combine that can optimize the combine processes normally controlled manually by an operator is one of the requirements that will enable the remote control of the combine initially allowing a relatively inexperienced driver to run a combine alongside an experienced operator who can remotely set the combine leading to some level of operating without a driver.

Claas' "Cruise Pilot" is a control system that optimizes a combine harvest performance based on one of three modes of operation: maintaining a constant ground speed, maintaining a constant throughput and Maintaining a constant throughput but minimizing losses. Claas' Cruise Pilot's constant throughput with losses mode monitors variations in the mass flow of crop in the feeder house along with grain loss information will change the harvesting ground speed automatically according to changing crop conditions to minimize grain loss and maximize harvest efficiency. The constant ground speed mode operates similarly to a cruise control on a car. Constant ground speed mode is used to maintain productivity in the form of area (acres or hectares) per hour, while the constant throughput mode maintains productivity by maintaining a constant volume or weight (bushels or tons) harvested per hour.

Similarly the New Holland's IntelliCruise™ automatic crop feeding system automatically matches forward speed to the crop load entering the header. By measuring the earliest possible indication of crop variation, the system ensures smooth changes of combine speed and allows top performance no matter how crop density changes throughout the field. Based on a set point determined by the operator, combine speed is decreased if the detected load is too high, or increased if the load is below the set point. Sensors on the straw elevator driveline measure the torque applied by the header and straw elevator to transport the crop toward the threshing system and automatically change the machine speed accordingly. In addition to freeing the operator from having to interpret the crop load and adjust the speed manually all day, IntelliCruise can reduce stress on the combine operations and even prevent jamming in heavy crop conditions..



2.2 ISOBUS III

The ISO-11783 standard (Tractors and machinery for agriculture and forestry - Serial control and communications data network) outlines a standard for communication on agricultural equipment. The means for communication is based on CAN 2.0B that was developed by Robert Bosch GmbH. This standard was built on top of the SAE J1939 standard for truck, bus and construction equipment powertrain communication. Overall the standard specifies a serial data network for control and communication between tractors and implements, utilizing a standardized method and format of data transfer. ISOBUS is the trade name that has been adopted to describe systems implementing the ISO-11786 standard. The standard specifies 3 main tractor-implement interface classes – 1, 2 & 3. For each class the Tractor Electronic Control Unit (TECU – Gateway controller between ISOBUS CAN and tractor CAN buses) is required to acknowledge a specific set of CAN messages. Each subsequent class adds functionality to the lower classes (for example class 2 supports all the messages of Class 1 plus a message subset particular to Class 2). Class 3 is currently the highest interface level and allows the implement to take control of certain tractor functions (e.g hydraulic remotes, PTO, 3-point hitch, steering, ground speed, etc.). The tractor is not required to provide access to all the implement requests control of but the standard provides a means for the tractor to allow the implement to take control if allowed/negotiated.

John Deere has partnered with a number of implement manufacturers (Pöttinger, Grimme, Amazon, Rauch, etc.) to develop and test Class 3 tractor-implement communication and control systems that provide higher levels of automation. In 2009 John Deere presented Tractor Implement Automation system at Agritechnica that allowed John Deere round balers to control the tractor speed and hydraulic remotes. John Deere, Grimme and Pöttinger won a gold medal at the 2011 SIMA show for presenting an enhanced version of the Tractor Implement Automation system that also allowed the implement to request control of the tractor steering. At Agritechnica 2011 John Deere presented further enhancements to their TIM system and announced that it now worked with 11 different implements. They have also implemented a security system that will only allow certified implements to take control of specific tractor functions.

Class 3 ISOBUS changes the way we look at the tractor-implement system. The implement that is performing a specific task is becoming more intelligent and is driving the overall tractor-implement system. The tractor and implement are becoming more integrated as a result and this allows for higher levels of automation and decision making. This improves the overall efficiency and productivity of the tractor-implement system and requires less supervision and skill from the operator.

3. Select History of some Autonomous Vehicle Projects

3.1 The Demeter project: 1994 – 2000

In 1994, Carnegie Mellon, NASA, and New Holland set a goal to mow and condition 40 ha (100 acres) of alfalfa in one continuous autonomous run. In August of 1997, using two complementary, mostly off-the-shelf guidance systems, a New Holland (NH) 2550 self-propelled windrower named Demeter (fig. 4), autonomously harvested the field in a single, continuous run. In 1998, Demeter autonomously harvested an additional 50 ha (120 acres) of sudangrass and alfalfa.

The National Robotics Engineering Consortium's (NREC) Demeter team at Carnegie Mellow University (CMU) consisted of a group of engineers and scientists. The NREC team's function was to implement the two guidance strategies along with a "task management" computer that worked with the NH 2550.

The New Holland team was a group of expert engineers who were very familiar with the NH 2550 used on the Demeter project. The NH team focused on the NH 2550 driveline to support integration of CMU's technology. In addition, the NH team provided knowledge-based experts on the NH 2550's operation in cutting hay and forage crops. They knew what the customers needed and why

What set the Demeter project apart from other similar research at the time was the use of two guidance systems, a task manager to plan and execute the path planning, and other controls required to successfully meet the project goals. A stereo vision based system was used for tracking the crop cutline, detecting the ends of rows, and detecting obstacles in front of the NH 2550. A control computer processed the input from a differential global position system (DGPS), a gyroscope, and wheel encoders were used to provide accurate position and orientation information. The DGPS position sensors were also used to validate the output of the vision system. A paper describing the technology used in the vision-based system is still available on the NREC's web site (**Figure 4**).

3.2 Autonomous Tractor/Planter Project with Univ of IL 1996 – 2000

CNH funded and actively participated in several guidance and autonomous vehicle projects with the University of Illinois in the mid 1990’s through 2000. Work conducted included the combining of GPS and vision systems on a Case IH 8920 MFD tractor (**Figure 5**), a 2WD Case IH 7720 tractor and a combine guidance project that used a Case 2188 rotary combine as the research vehicles where the vehicles were modified to incorporate electrohydraulic steering, vehicle guidance sensors and the associated control equipment (Benson, Stombaugh, Will).

3.3 DARPA Grand Challenge (2004-2005) and Urban Challenge (2007)

The US Defense Advanced Research Projects Agency (DARPA) was given authority by US congress to offer a $1 million prize to any team that could build a fully autonomous (unmanned) vehicle that could complete a 150 mile off-road course within a limited time period. This competition was given the name DARPA Grand Challenge. The objective of the project was to rapidly advance robotic developments with the goal of making one third of ground military forces autonomous by 2015. The first event was scheduled for 3rd November 2004 and was held in the Mojave Desert. More than 100 teams applied to compete in the first competition. No team completed the course in the first DARPA Grand Challenge.

The second DARPA Grand Challenge was held on 8th of October, 2005 and the prize for first place was increased to $2 million. The course in 2005 was held on roads that were generally narrower and had more curves than the 2004 course. 5 vehicles completed the course in 2005, with Stanford University taking first place by completing the course in 6 hours 54 minutes.

The third competition of the DARPA Grand Challenge was called the “Urban Challenge” and took place on the 3rd of November 2007 at George Air Force Base in California. The 60 mile course for this challenge traversed an urban environment and required competitors to obey road rules and navigate through traffic and around obstacles within a 6 hour time limit. The vehicle software for this challenge had to make more intelligent decisions than the prior Grand Challenges as the environment was a lot richer with other vehicles and objects. Each team was given a map of way-points at the beginning of the competition. Tartan Racing (Carnegie Mellon University & GM) took first place with Stanford University placing second.

4. Near term autonomous applications – being developed and demonstrated

4.1 Automated unload on the go

Several companies have publicly shown and discussed combines remotely controlling tractor/grain carts position and speed during the unloading of grain from the combine to the grain cart on the go with varying levels of supervision. The first public discloser of the combine remotely controlling the tractor was at the 2011 SIMA show in Paris France where Case IH won a gold medal. Central to the system is a wireless connection, used to manage data exchange between the combine and tractor. The combine takes control and dictates forward speed, vehicle alignment and direction of travel to the tractor when it enters the 'active zone' for a hands free operation.

The main advantage of this system is consistent and repeatable unloading on-the-go during the harvesting as the individual tractors/grain carts arrive at the combine. Even with unskilled operators it is possible to perfectly fill trailers and avoid spilling the valuable crop over the edge of the cart/trailer. This system eliminates the risk of tractor and combine collisions due to precise vehicle alignment and it also reduces operator stress, crucial during harvest when farm staff are putting in long hours.

At the 2012 Farm Progress Show John Deere announced their “MachineSync” which also establishes a combine to tractor communication link with radios that enables the combine to synchronize speed and lateral position of the tractor while unloading the grain from the combine to the cart.

4.2 Robotic fleets for highly efficient agriculture and forestry management: EU 7th Framework Program 2010 – 14 (RHEA)

RHEA is a FP7 project devoted to the application of Precision Agriculture techniques. For that, RHEA is focused on the design, development, and testing of a new generation of automatic and robotic systems for both chemical and physical –mechanical and thermal– effective weed management in agriculture and covering a large variety of European products including agriculture wide row crops (processing tomato, maize, strawberry, sunflower and cotton), narrow row crops (winter wheat and winter barley) and woody perennials (walnut trees, almond trees and olive groves).

The consortium brings together the expertise and knowhow of 19 working groups belonging to 15 organizations (Large-scale integration Collaborative project) from 8 European countries with a deep background in topics covering specific expertise in robotics, agronomy, perception and action, manufacturing of agricultural equipment and end-users. The consortium includes 8 SMEs that share 45% of the total budget and an industrial partner.

4.3 Kinze autonomy hHarvest system

In a “Press Room” news release by Sherry Mertens on the Kinze website a field day was described where Kinze® Manufacturing, Inc. demonstrated several modes of autonomous vehicle operations on a farm in Monmouth, Ill. Video clips of the demonstration can be found on You Tube (http://www.youtube.com/watch?v=YFy6ZAjbeew). Taking the Case IH and John Deere unload on the go systems one step farther the Kinze Autonomy system has a tractor/grain cart that autonomously follows the combine until the combine is ready to unload then the autonomous tractor/grain cart speeds up and synchronizes with the combine during the unloading of grain and with further instructions for the combine operator the tractor/grain cart can proceed to the edge of the field and wait for further instructions.

4.4 Fendt GuideConnect

At Agritechnica 2011 Fendt won a gold medal for their GuideConnect. Fendt GuideConnect is a system where a tractor with an experienced operator is followed by a drone tractor. The Fendt GuideConnect uses two of the enabling technologies already discussed: a very accurate RTK-GPS positioning system and a wireless communication system between the two vehicles. Fendt has indicated the possibility of several GuideConnect systems being available in Germany in 2013. A video clip of the Fendt tractors can be seen on You Tube as well (http://www.youtube.com/watch?v=HjY-UBWUTvM).

4.5 The spirit autonomous tractor

One of the big attractions at the 2012 Big Iron farm show was the autonomous tractor Spirit. Even though it was not in the field, farmers sought out the remote controlled tractor. Terry Anderson, with Autonomous Tractor Corporation of Fargo, says this is an innovative piece of equipment. "We started this project 13 years ago to see if we could build a more economical, more reliable, easier to maintain tractor, and we ended up building a diesel, electric tractor with twin 202 hp (150kW) engines, 404 hp (300kW) that can be pushed to 500 hp (370kW) if you want, on tracks that has a non-GPS guidance system.” The tractor, called The Spirit, uses lasers and four transponders in the field for guidance. Autonomous Tractor Corporation plants to start building tractors in March 2013. Anderson hopes to price the 400-hp tractor at about $200,000, about half the price of the more traditional 4WD tractor with a cab and he thinks he can offer a 25,000 hour warranty.

5. Conclusions and closing comment

The developments in agricultural machine automation are building a solid foundation for the development of autonomous agricultural machines. Research in the field of autonomous agricultural machines has been very active in the last 10 years. Some researchers are investigating the use of swarms of small agricultural machines or robots while others are looking at automating current production tractors similar to what many farmers are using today. There still are concerns regarding liability and collateral damage that could be caused by a "runaway" vehicle but there is active discussions and legislation starting to address some of the liability concerns. As the automotive industry pursues autonomous vehicle technology and educates society about the technologies and precautions being taken, society will become more accepting of the idea of unmanned vehicles. As skilled labor becomes harder for farmers to find the demand for autonomous agricultural machines will increases. The potential benefits of autonomous agricultural machines are driving the industry to develop these technologies.

With commercially available autonomous vehicles and functions being announced and demonstrated along with smart crop sensors, telematics, vehicle to vehicle wireless networks and the automatic control of crop engaging harvesters it will only be a short time before drone harvesters are following experienced operators in the field and autonomous vehicles are in the field running missions.

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Figures 1, 2, 3 - On the left is what the human eye sees. The digital image generated by the 3D camera system is in the center. The colors give an exact picture of the distance and the degree of filling of the silage. The picture on the right is the system working in the field

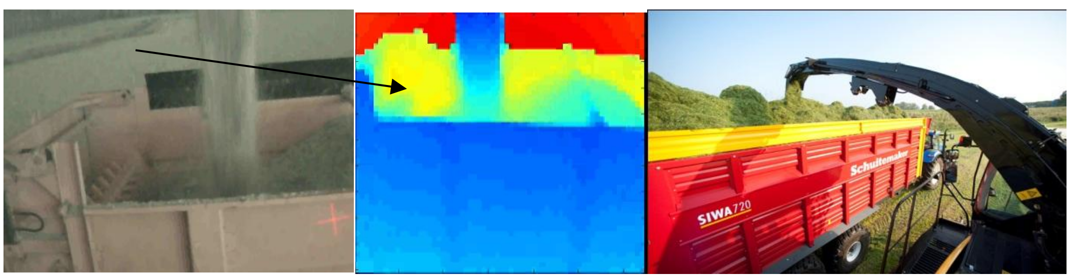

Figure 4, 5 - Demeter the autonomous NH2550; Autonomous CIH tractor