An Autonomous Electrical Vehicle Based on Low-cost Ultrasound Sensors for Safer Operations Inside Greenhouses

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Abstract
The main target of this research activity is to develop and test different low cost sensors that can enable a multifunctional tracked electrical vehicle to move autonomously inside a greenhouse with tomatoes cultivation. Big effort has been put on finding solutions that require minimum or no apparatus installation in the greenhouses while performing centimetre-level accuracy at a fraction of the cost of a DGPS commercial system. The used low cost sensors are described, while description of the electrical vehicle and its capabilities can be found in previous works.
Two main kinds of sensors systems have been developed using low cost ultrasound sensors. The first system uses a set of eight ultrasound transmitter/receiver couple. These sensors can compute time by time the distance and the rotation angle of the robot with respect to the plants rows. This information could be used to correct the robot trajectory, allowing the system to move along the centre line between rows.
The second system that has been tested is a Local Positioning System (LPS). It uses a set of low cost ultrasound receiver sensors mounted on the greenhouse structure in a regular grid while an ultrasound transmitter is mounted onboard the robot that is moving between rows. The system allows to know the relative coordinate of the robot with respect to a reference inside the greenhouse. At this stage, different trials on the sensors have been performed inside a greenhouse in different condition; these trials allowed to evaluate systems accuracy and performance.

Introduction
Greenhouse activities often require hours of hard-work made by operators. Many of these works also can be very dangerous and uncomfortable because of chemicals, high temperature and humidity. With this environmental condition, even normal agricultural operation can became heavy and stressful. Moreover, because of high temperature and humidity, when they are required, operators often do not wear safety clothes, increasing health risk [Sammons *et al*., 2005].

In this condition an assist machine could be useful for operators in order to alleviate the work load. For example an autonomous machine can automatically perform chemical spraying tasks inside greenhouses, avoiding the presence of operators; otherwise it can perform transportation tasks, plants health check, environment check and so on.

To mitigate problems related to spraying tasks, in recent past, some semi-automatic distribution methodologies, based on some fixed facilities built inside each greenhouse, have been developed. These can operate without human intervention and are composed by a number of sliding rods with nozzles [Sammons *et al*., 2005]. Due to their high cost and huge impact on the greenhouse, they are not so common. Instead, because of greenhouses environments are highly structured and regular with respect to the open field, they are well suited to be operated by some automatic machines that do not implies much fixed cost for each greenhouse. Moreover automatic machines can be re-used in different place and can solve tasks other than spraying.

In [Pedersen *et al*., 2008] economical impact for different automatic approach in agriculture for different parameters (fuel consumption, labour costs, autonomy, chemicals cost, maintenance) is analysed against manual approach. In the last decade, different research group have been interested on these issues. The Aurora robot (Spain) is able to perform different tasks in an autonomous way with remote supervision [Mandow *et al*., 1996]. Within the Italian project Agrobot, a mobile rover bringing a 6 DOF manipulator with an end-effectors and a 'head' with 2 DOF, was developed. The system is dedicated to tomato cultivation inside greenhouse. The robot is able to inspect each plant and to plan individual treatment. Moreover it can distinguish the different maturity level of the fruits. In order to solve navigation problem, some visual feedback have been used [Dario *et al*., 1994]. At University of Genova a project named "Mobile robots in greenhouse cultivation: inspection and treatment of plants" [Acaccia *et al*., 2003] has been developed. In this work chemical hazard for operators and the usefulness of unmanned or human assisted operation by means of a support machine, is highlighted. The main target of the system was to monitor the health status of the plantation in order to plan dedicated treatment with precision farming methodology. Moreover the system can monitor the chemicals concentration inside the greenhouse and give information about the possibility for human operator to enter or not. That machine is powered by means of an internal combustion engine. A mobile platform for greenhouse chemicals spraying has been developed at University of Almeria [Sanchez *et al*., 2010] In this work, specifications for a greenhouses robot are first identified then the complete machine (named FitoRobot) has been built with ultrasonic sensors for the motion between plants rows. The machine is driven by an internal combustion engine. A commercial machine, named Fumimatic 400 [Fumimatic], is available in Spain. It is not autonomous nor teleoperated but it is a complete spraying machine with a powerful Diesel engine and a 400 l tank for chemicals.

In [Schillaci *et al*., 2009], [Balloni *et al*., 2008], [Balloni *et al*., 2009] a multifunctional electrical vehicle, named U-Go Robot, designed and realised at DIEES Robotic Laboratory in cooperation with DIA, is described. With a suitable choice of batteries, motors and control system, high payload (about 250 kg), high working capabilities (about 8 – 9 hours), suitable speed and manoeuvrability have been obtained using a tracked vehicle. Moreover electrical motors are well suited to work inside the confined space of a greenhouses because of they do not generate exhausts. Once the robot has been built, different navigation methodologies, mainly based on DGPS and 2D laser scanner, have been tested with good results [Schillaci *et al*., 2010]. The only drawback of these solutions is their high cost.

In next section, two different low cost solutions, both based on ultrasound sensors, for robot autonomous navigation in tomatoes greenhouse cultivations, are described.

Self-centering system

The first sensor system is composed by eight SFR08 sensors from Devantech and exploits the particular environment of tomatoes cultivation in greenhouse. Generally speaking, the system can operate in all those places where a wide, quite regular, vertical leaves surface is available.

Each sensor is a module that comprises both transmitter and receiver transducers and all the related electronics in order to perform distance measurement in the range 0.03 m – 6 m. The used ultrasound wave is in the 40 kHz band and the radiation diagram of the transducers is quite large. The module uses the acoustic wave generated by the transmitter and reflected by an obstacle in front of the module itself, to measure the distance by means of the wave time of flight (about 300 m/s in free air). The sensor module is shown in Figure 1.

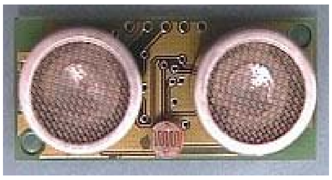

Figure 1. The SFR08 sensor module

Exploiting these features it was possible to use this sensor to measure distance against leaves walls. Due to the wide area covered by the sensor, the single measurement is not biased by the particular leaf or by local leaves structures but it takes a kind of mean value of the distance. In more detail, in the particular area covered by the sensor, if a single small leaf is on a different plane with respect to the most leaves vertical plane, its position will be neglected by the sensor because of the very small acoustic energy it can reflect; in fact the module has a threshold below which it cannot 'see' targets in front of it.

Using these considerations, a set of eight sensors and a small electronic board that collect data from each sensor, were mounted around a wooden-made robot mock-up (used only for testing purpose). In Figure 2 the experimental test-bed is shown. The front and rear sensors, during these experiments, are not used but they can be useful for safety reasons to avoid collision of the robot with obstacles and operators.

Figure 2. The experimental setup with eight SFR08 sensor modules

The other six lateral sensors are used in order to compute the position of the robot with respect to the plants rows. Each sensor measures its distance to the plants and all these measures, using some filtering algorithm and some trigonometric consideration, give back the robot position (offset with respect plant rows) and orientation. Actually only two lateral sensors could be necessary for this algorithm; the third sensor (the central one) is used for validating measurement of the other two and to compensate for wrong measurement that can happen. Information about robot offset and orientation are then used to correct the robot trajectory, allowing the system to move between rows. In Figure 3 and Figure 4 some data acquired during the real experiment are shown. During these tests, the eight sensors were put between the two rows with different orientation and offset. At the same time, the real position was measured by using the ultrasonic sensors and by using a rule and a goniometer. Using this methodology, it was possible to evaluate system performances and accuracy.

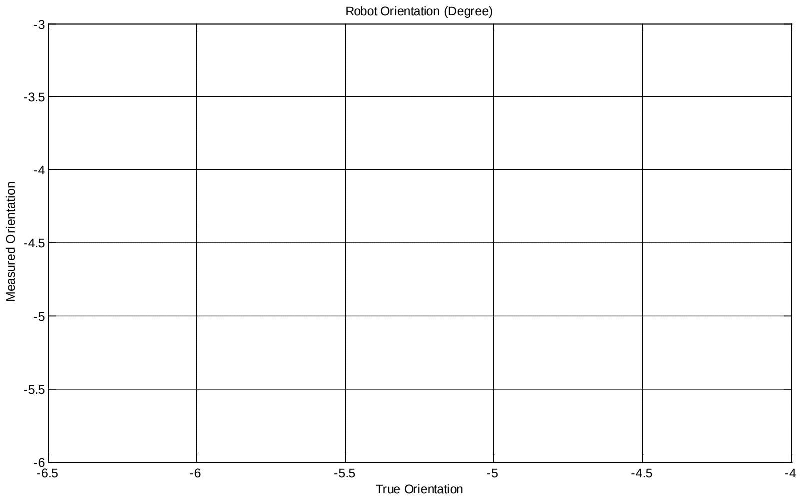

Figure 3. Orientation test: on the X axis there is the true orientation of the robot while along the Y axis there are orientation measures by using the SFR08 sensors

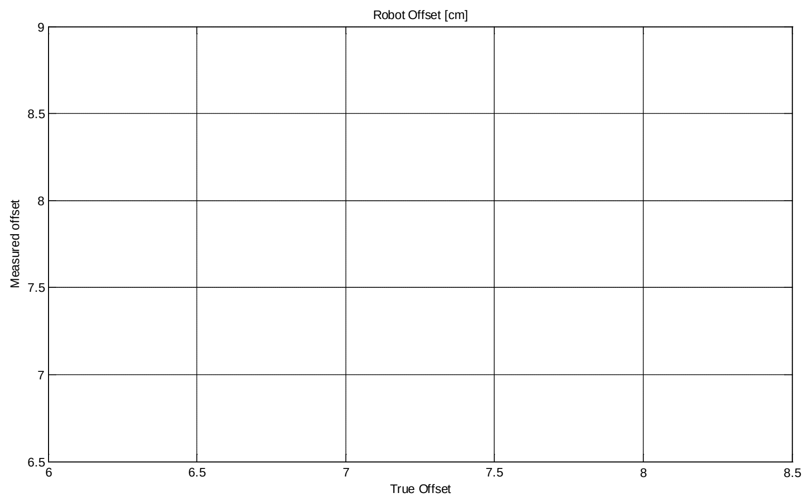

Figure 3. Offset test: on the X axis there is the true offset of the robot while along the Y axis there are offset measures by using the SFR08 sensors

The LPS system

The second system that has been developed is a Local Position System. Like the most common GPS system, the LPS give back the position of the system, for example the robot, while moving or standing still. The main difference is that the GPS uses absolute coordinates while the LPS uses relative coordinates with respect to a reference system locally defined, for example one of the vertex of the greenhouse [Parisek *et al*., 2009]. The LPS system that has been used was developed at DIEES during past research activities for different applications [Andò *et al*., 2006], [Andò *et al*., 2008], [Andò *et al*., 2009]. The system does not rely on some special structure of the greenhouse, but it can be used in all kind of environment indoor or outdoor. Moreover different tests performed in real greenhouse has shown that plants, cable, pipe and other infrastructures that normally can be found in every greenhouse, does not interfere with normal system operations. The LPS system uses a set of low cost ultrasound receiver mounted on the greenhouse structure in a regular grid (for example one sensor on each pillar). An ultrasound transmitter is then mounted on the robot that is moving between rows; every time the fixed receivers hear the signal sent by the robot, the system computes the robot position with respect to the reference system using a trilateration algorithm. Using the robot position and as the greenhouse map is known, it is possible to use standard navigation algorithms used for outdoor DGPS navigation, exploiting the same centimetre-level precision at a fraction of the cost of a DGPS commercial system.

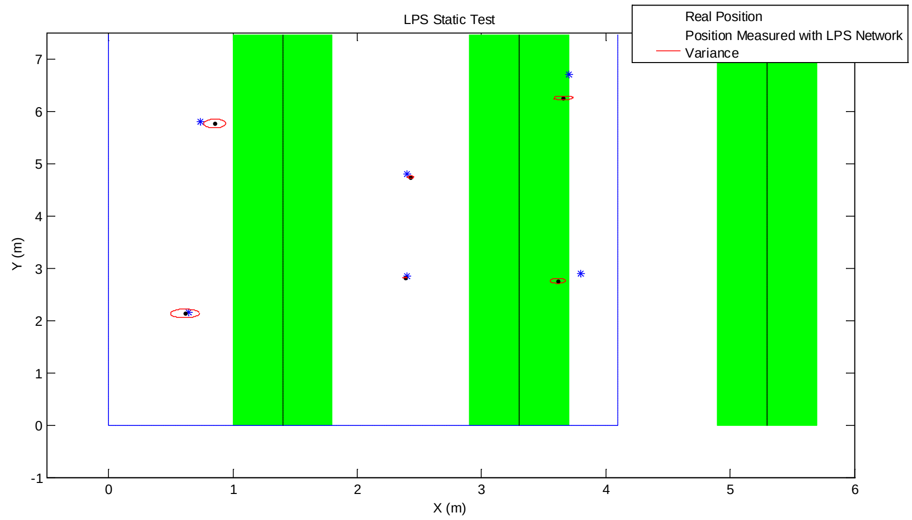

Figure 5. LPS system: static test.

Different tests have been performed in a greenhouse in order to validate the system capabilities. Eight fixed receivers have been mounted inside the greenhouse covering an area of about 14 m^2. Static tests have been performed in order to evaluate the system accuracy. The mobile transmitter has been placed on different position inside the area covered by the fixed sensors.

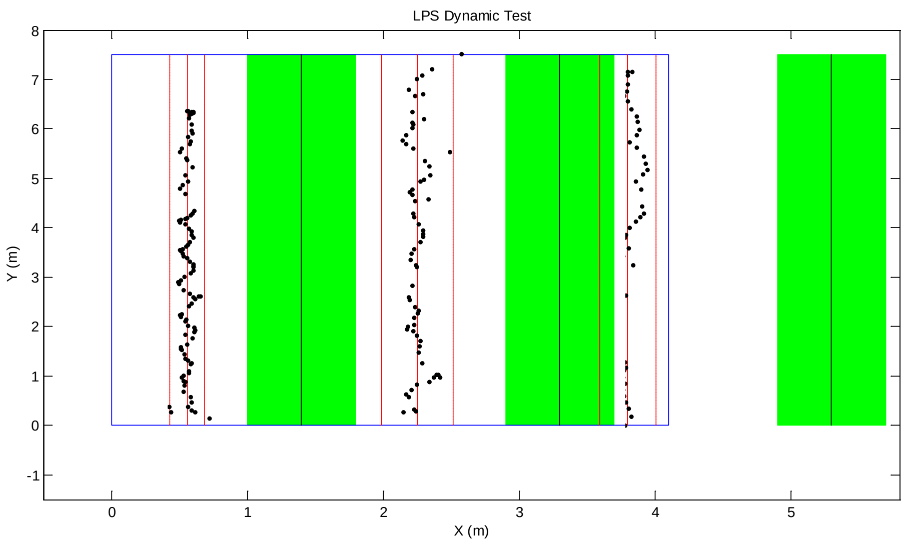

Figure 6. LPS system: dynamic test.

The real position has been measured with a rule and compared with the position estimated by the LPS system. In Figure 5 some results are shown. In Figure 6 the results of a dynamic test are shown. In this case, the mobile transmitter has been moved along rows and subsequent positions have been recorded. Dark dots represent the system measurement, while the solid line represents the trajectory mean value. Dash-dot lines represent the data variance. In both figures, green boxes represent the plants.

Conclusion

In this work, two special sensors systems for automatic guidance of an electrical vehicle have been shown. Sensors like DGPS and 2D Laser scanner are widely used and the Authors performed different test in other works. They have very good performance but the high cost and their use cannot be addressed to most SME in the agriculture field. The two methodologies proposed here are instead based on very low cost ultrasound sensors and suitable measurement algorithms. They allow to obtain the position of a moving machine along rows with respect to corridors boundary or with respect to a reference system defined in the greenhouse. The two systems can be used at the same time on the same machine for a better accuracy (smart data fusion algorithm could be developed) or it is possible to use only one of the two at time.

Different tests have been done in a real greenhouse in order to evaluate performance and capabilities of the two systems and results have been reported; the obtained accuracy is in any case in the order of few centimetres.

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