EFFECTIVE SUPERVISION OF A TRACTOR FLEET

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Abstract. This paper describes a supervisor system to monitor automated agricultural vehicles. The supervision system consists of a program that gathers and analyzes, continuously and in real time, the information provided by subsystems on board the vehicles, and notifies the user when it detects a failure, such as an inappropriate working speed or the wrong valve state. To develop this system, a modular and hierarchical architecture is proposed and used. Simple low level supervisors, only able to detect easy failures in small systems, are combined to build more complex, higher level supervisors able to detect more complex problems. The system was tested with automated tractors during the execution of a real agricultural task, spraying herbicide for selective weed treatment. The system successfully supervised the task, detecting the failures that arose. According to these results, it is concluded that the system proposed is a highly useful tool to manage fleets of agricultural vehicles.

Keywords: Supervision; Tractor fleet; Modular and hierarchical architecture.

1 Introduction

Using robotic agricultural machinery to automate agricultural tasks is today an ever closer reality. The potential of automated machinery to outperform customary human labor promises to increase farm productivity. For this reason, many research projects have undertaken work on this subject in recent years (Demeter, 2000) (CROPS, 2010) (RHEA, 2010). For example, in the RHEA project, all the components of a fleet of autonomous drones and tractors work together to totally automate selective treatments in wheat, maize and olive fields.

It is important to note that performing agricultural tasks without human staff and delegating the responsibility to machines presents a real challenge since much of the machinery used in agriculture is heavy and mobile, and is therefore highly dangerous. In addition, working in an uncontrolled outside environment (weather, people working nearby, uneven ground, animals that can appear suddenly, etc.) makes it even harder to maintain safe conditions for equipment, people and the crop itself, and also makes the automation and the quality of the tasks more complex. With so many things to pay attention to, the human operator in charge of supervising the automated task needs some kind of system to help keep everything under control, even more so when the task is to keep a fleet of tractors working together.

In this paper some important aspects of the supervision system developed for the tractor fleet of the RHEA project are described. The supervision system has been implemented using a combined modular and hierarchical architecture based on
multiple supervisors working in parallel and on different supervision levels: basic, vehicle and fleet level. The supervisors of the basic level are focused on only one property (trajectory, speed, valve, engine, etc.) of the different elements that compose the ground robot (mobile platform, implements and perception system). At the vehicle level, supervisors detect higher level failures that arise from different properties of the same vehicle. Finally, at the fleet level, supervisors detect the anomalies with regard to the whole fleet behavior.

In the following sections the proposed architecture for the supervision system is described as well as some initial results of the system performance.

2 The Supervision Architecture

Two concepts are essential to understanding how the proposed supervision system works: alarms and supervisors.

An alarm is the notification generated when a failure is detected, such as an inappropriate speed, a tractor out of track or the wrong valve state. In addition to failures, an alarm can also notify an operator of any important change detected even if it is not an incorrect situation, e.g., a completed trajectory or a successfully initialized device. Throughout the document, most of the alarms explained are related to failures, and those that do not refer to malfunctions are explicitly indicated.

A supervisor is the module or piece of code that analyzes the information periodically received from the entities to be supervised (real entities, such as an engine, a tank, a valve, etc., or abstract ones such as trajectories, collisions, etc.) and generates an alarm if a failure is detected. A supervisor is mainly composed by a set of IF-THEN rules that generate alarms when the information collected meets some condition.

In general, the input of a supervisor can be expressed as a pair (property, value), where property indicates the entity to be supervised and value its current state. Note that a supervisor is also considered a subsystem and thus its outputs can also be used as inputs for other supervisors.

The supervisor outputs are the alarm notifications. A supervisor can output several kinds of alarms, but, in general, the higher level supervisors generate more kinds of alarms than the lower ones since they supervise more complex entities and hence they find more kinds of failures.

3 The Proposed Supervision System

The supervision system implemented is a fleet level supervisor that brings together the alarms generated by all the other supervisors. Some of these other supervisors belong to the same supervision level whereas others belong to lower levels. Figure 1 shows the internal structure of the implemented system. In this figure, each of the rectangles represents a supervisor and the arrows represent the inputs and outputs of the supervisors, all of them alarms except the information provided by the sensors.

Five different levels are shown in the figure: user, fleet, vehicle, basic and sensor level. The developed supervision system covers the fleet, the vehicle and the basic levels. The sensor level contains the devices that provide the information required by the supervisors to know the status of the equipment. Finally, the user level contains
the systems that receive the alarm information generated by the supervision system to be shown to the operator through a GUI.

Fig. 1. Supervisor system architecture.

In addition to the information provided by the sensors and the internal systems, the supervisors can also access mission data. The mission is the agricultural task that the fleet must carry out, and it is mainly composed of a plan with the expected trajectories for each of the vehicles, the speeds of each vehicle and the state of the implements for each point of the trajectories, that is, if the boom has to be activated or deactivated, if the valves have to be opened or closed, etc. This information is static, in other words, it does not change during mission execution and it is loaded by the supervisors (if required) at the beginning of the supervision.

The architecture proposed is modular since each supervisor encapsulates some logic of the supervision, and they all can be replaced easily. Moreover, the architecture is also hierarchic, since the supervisors can be linked to each other to build more complex supervisors performing at different supervision levels. By combining modularity and hierarchy, any supervision system built with the proposed architecture can be easily adapted and updated to provide new super-vision facilities.

The supervisors that run the overall supervision system are detailed below.

3.1 Basic Level Supervisors

The basic level supervisors supervise the following properties: speed, out of track trajectory, connection disruption, implement state and trajectory completed.
The speed supervisor receives the speed from the speedometer of the vehicle and the current position from a RTK GPS installed onboard. Since the supervisor also knows the expected trajectory with the expected speeds, it checks periodically if the speed received matches the expected speed (within a difference margin) for the current position of the vehicle. If they do not match, an alarm is generated.

The out of track supervisor periodically checks if the current position of the vehicle received from the GPS matches with the expected position on the mission trajectory. If some point is missed or is visited out of order, an alarm is generated. A point is visited if the vehicle position is close enough to the point, considering a set threshold. Note that the RTK GPS can report the vehicle’s current position with an accuracy of 2 centimeters and with a frequency up to 20 Hz, so, properly adjusted, it is impossible for a vehicle to move far without being detected by the supervisor.

The connection disruption supervisor periodically checks, using a timer, when a sensor or an internal system last provided its information. If some critical time is exceeded, a connection disruption alarm will be issued. Note that the overall system supervises on-moving medium-size tractors, and therefore it is essential to receive important information like tractor position with the appropriate frequency.

The speed supervisor is similar to the implement state supervisor, i.e., it checks if the vehicle’s speed matches with the expected speed in the plan.

Finally, the trajectory completed supervisor checks if all the points on the mission trajectory are visited. If this condition is met, an alarm will be generated. Note that this alarm does not represent a malfunction in the system, and it is used to notify the operator that the vehicle has completed its assigned trajectory. This supervisor is not forced to check if the points are visited in the right order, but if the order is wrong, the out of track supervisor detects the error.

Finally, note that the lowest level supervisors are simple, separately detecting minimal deviations; however, working together, they are a very powerful tool that covers a wide spectrum of situations.

### 3.2 Vehicle Level Supervisors

In the current implementation, this level only contains the supervisors that bring together all the alarms related to a given vehicle, so, in general, this level will contain as many supervisors as vehicles there are in the fleet. These supervisors are helpful to encapsulate all the supervision involved with a vehicle.

In the more complex version of the supervision system, more supervisors must be included. An easy example that illustrates the need for new supervisors is the case of a “pilot flame” alarm in a mechanical-thermal tool. The alarm is generated when the pilot flame is shut down, for example, due to a gust of wind. In this case, the fault is detected and automatically repaired by the actuation system (mechanical-thermal tool) re-igniting the pilot flame. However, if the problem persists due to a tool malfunction, the situation can only be detected at a higher level.

### 3.3 Fleet Level Supervisors

The fleet level supervisors considered in figure 1 are: the collision, the mission completed and the fleet supervisors.
The collision supervisor receives the positions of all the vehicles in the fleet and checks two by two if they are separated by less than a given distance. If so, an alarm is generated.

The mission completed supervisor receives its inputs directly from the vehicle supervisors immediately below its level, i.e., it receives the trajectory completed alarms. It only generates an alarm if it receives the trajectory completed alarms for all the vehicles in the fleet, in other words, when the mission is finished. This supervisor reports to the operator when all the vehicles have completed their trajectories.

Finally, the fleet supervisor brings together all the alarms related to the fleet. It is helpful to encapsulate all the supervision in a single supervisor.

4 Results

To test the supervision system developed, a mission within the RHEA project scenarios was selected. A tractor carrying an herbicide spraying bar had to cover a field and spray the herbicide with precision, just on the weed patches. Figure 2 shows the expected trajectory of the mission and the positions of the patches.

![Fig. 2. Mission trajectory and weeds patches positions.](image)

The field in the scenario was shortened to maintain a trajectory with only one turning maneuver to better show the results without undermining them. A bigger field would only show more instances of the same results.

Figure 3 shows the results obtained for the speed supervisor. The expected speeds were 2 km/h on the headers and 3 km/h inside the field, and the maxi-mum speed error (threshold) was set to 0.5 km/h.
The inputs received over time, the real speed of the tractor (in red color) and the expected speed (blue), are displayed at the top of figure 3. At the bottom of the same figure, the output alarm generated is displayed in green. The figure shows that the alarm is issued mainly on the headlands. On the headlands the auto-mated tractor tested did not reach the expected 2 km/h, sometimes due to the small space for accelerating, other times due to the limited capabilities of the tractor to follow the demanded speed (the RHEA project is an on-going project and some aspects of the autonomous navigation are still under development). The speed supervisor successfully detected the differences between both signals and generated the alarm when the difference was larger than the set threshold.

![Graph showing speed supervisor inputs and outputs](image)

**Fig. 3.** Speed supervisor inputs (real and expected speed) and outputs (alarm).

Figure 4 shows the results for the implement state supervisor. The real and expected states of the valves are shown in red and blue, respectively, as well as the alarm activations/deactivations, in green, over the mission time. The real and expected states were nearly the same values, however, there are some small differences during the activations/deactivations of the valves. These differences were due to the delay associated with the response time of the valves and were successfully detected by the supervisor.

Figure 5 shows the results for the out of track supervisor. The distance to determine if a point was visited or not was set to 50 cm. The real and expected trajectories are shown along the mission time, in red and blue, respectively, as well as the alarm activations/deactivations, in green. Since the tractor was able to follow the expected trajectory very closely, the expected turn trajectory was modified to force the supervisor to detect out of track alarms. As shown in the figure, the supervisor detected perfectly the out of track positions.
Fig. 4. Implement state supervisor inputs (real and expected state) and outputs (alarm).

Fig. 5. Out of track supervisor inputs (real and expected trajectory) and outputs (alarm).
Figure 6 shows the results for the trajectory completed supervisor. As shown in figure 5, all the points inside the field are visited and then the alarm reporting that the trajectory was completed was generated. Note that the supervisor was defined to check only the points inside the field because the trajectories in the headlands did not affect the treatment (it did not matter if they were visited or not).

![Fig. 6. Trajectory completed supervisor output.](image)

Finally, figure 7 shows the vehicle supervisor that brings together all the alarms generated with regard to the tested vehicle.

![Fig. 7. Alarms generated by the vehicle supervisor.](image)

5 Conclusions

The supervision system designed and developed was able to detect different failures, dangerous situations such as tractor out of track positions, inappropriate working speeds or wrong states on the implements. The supervision system also detects important inflection points such as whether the trajectory demanded was completed or the mission ended. Furthermore, the modular and hierarchic architecture proved to be a very useful framework to incrementally implement complex supervisor systems from lower level and simpler supervisors. Consequently, the supervision system could easily be extended to detect any kind of failure by just adding new low supervisors.

From these results it can be concluded that the supervision system as well as the architecture are highly useful tools to supervise agricultural vehicle fleets.

As future work, the supervisor could be easily integrated with an upper layer of decision-making software to form an overall farming control system able to detect and neutralize failures in real time. Moreover, a test of the supervisor system with a fleet, i.e., with several vehicles, is still pending. Finally, some easy constraints could be added to some of the supervisors to avoid the emission of the alarms when it is not
clear they needed to be issued; for example, the supervisor of the state of the implements could take into account the delay in the response of the valves by allowing for some response time difference.

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