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A NEW MECHATRONIC APPROACH FOR UNDERLIEING DECISIONAL PROCESSES IN PRECISION AGRICULTURE

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Abstract: *The concept of precision agriculture implies the elaboration of soil fertility maps which are site-specific to certain soil lots. These maps have to be elaborated with great spatial consideration and with the help of the GPS technology. By means of using this technology, topographical data concerning the fertilizer consumption amount is being acquired, and also data which serve to irrigation optimisation or even real time mitigation of unwanted weather effects. This article is about the conception and development of a system meant to be able to determine the soil nutrient quantity for each culture and the development of statistical predictions for potential productivity of different culture types on a certain soil lot.*

Key words: *mechatronics, data acquisition, prediction, decision, precision agriculture.*

1. Precision Agriculture Development and Technology So Far

As of late, due to increasingly harsh environmental regulations, both nationally and internationally, the precision agriculture has become one of the main solutions for mitigating the unwanted effects of chemical fertilisation of agricultural soil.

This branch of agricultural science has gradually become what now experts call to be the future of modern soil processing. By using fertility maps of the soil, the modern farmers can accurately use differentiated fertilizing techniques, instead of the old methods which involved uniform fertilizer spread.

In essence, the old techniques led to excessive fertilizer concentration in areas where the soil was naturally fertile, or on the contrary, to insufficient fertilizer concentration in soil areas where it was most needed [1]. In terms of environmental issues, it may be stated that the excessive concentrations of nitrogen and carbon in some areas of the soil led to chemically imbalanced crops which, in long term, could have had a serious impact on the health of the consumers.

This branch of agriculture has undoubtedly spawned a new trend in technological research and development. As a result, there are already a few important development ways for the technology involved in this field.

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2. Most Commonly Used Precision Agriculture Equipment

The most important technological advances in precision agriculture technology and machinery have led to soil E.C. mapping equipment, soil *pH* measurement and mapping technology, and spectrophotometers. Although these are the most commonly spread equipment types, one should always remember that different customers have different needs. As a result, a large part of the precision agriculture technology currently available is custom made for a certain application or certain soil/land characteristics.

2.1. Soil E.C. Mapping Equipment

As defined on the website of one of the world's largest manufacturer of P.A. technology [5], soil E.C. is soil electrical conductivity - a measurement of how much electrical current soil can conduct. It's an effective way to map soil texture because smaller soil particles such as clay conduct more current than larger silt and sand particles. By far, the soil E.C. mapping equipment leads to one of the most interesting research directions, and it has provided the necessary theoretical and technological basis for the development of other technological equipment. Generally one can describe the E.C. soil mapping process by highlighting the working principles behind the technology: the equipment is outfitted with one pair of coulter-electrodes which injects a known voltage into the soil, while other coulter-electrodes measure the drop in that voltage. A computer connected to the system uses smart integrated GPS technology and advanced software to correlate the soil E.C. readings with the precise spatial position of the location where the E.C. was read. The result: a detailed map of the soil texture variability in the crop rooting zone. Optionally, the map along with the most important physical and chemical characteristics of the soil can be included into a computer virtual model which is commonly known as a GIS (Geographical Information System). Soil E.C. applications are as varied as the fields they map: fruit growers use them to select root stocks, wheat growers use them to guide deep nitrate sampling, cotton growers use them to variably apply nematicides, and the list goes on. If soil texture affects a farmer's crops and its inputs, soil E.C. maps are the base layer for precision management of that farmer's fields.

2.2. Soil *pH* Mapping Equipment

The typical soil *pH* sampling method involves manually taking soil samples every 100 meters. Further steps in this process involve using specialized computer software to fill in the gaps to make a functional *pH* spread map. However there is a serious problem on most fields: *pH* varies more than grid sampling can handle. This means that the *pH* levels may vary significantly inside the 100 meters sampling intervals. The ever present need for data precision has demanded that when 1 ha grid lines are overlaid on *pH* maps from the *pH* mapping equipment; the *pH* variability within each grid should be fully exposed. It is also important to understand that in each grid *pH* can vary as much as it does in the entire field. The design of modern precision agriculture equipment is similar to the soil E.C. cartographer. However, as a main feature, it has a sampling device (similar to a probe shaped like a shoe) which is specially designed to collect soil samples and measure soil *pH* levels. The working principle is that the hydraulic cylinder pushes the probe in the ground, so that soil flows through it. When the cylinder picks up the probe, the soil in the "shoe" trough is pressed against *pH* electrodes. After a few seconds the shoe is lowered again to collect more soil. As it does, the new soil coming in, moves the previous soil sample out the back of the shoe trough, and spray nozzles clean the *pH* electrodes. The shoe raises, and the process is repeated, with no action from the operator and no stopping.

2.3. Spectrophotometers

Spectrometers are being used in commercial agriculture today: in milling, forage, meat processing and more. However, the use of this kind of equipment to measure soil properties is relatively new. Researchers in laboratory settings have found visible and near-infrared reflectance (VIS-NIR) measurements of soil samples correlate to important soil properties such as carbon and nitrogen. Therefore precision agriculture technology has been using spectrophotometers as a means to move these measurements out to field research, thus providing a platform for research into soil properties as they vary within a field. Payments for soil carbon enrichment may also represent an additional source of farm income, as provided carbon can be measured accurately. Someday, similar technology may be used to augment or replace traditional lab analyses for other soil constituents. The working principle behind this equipment is the following: when light hits soil molecules react, they vibrate. This vibration absorbs some of the light, how much light is either absorbed or reflected depends on the chemical soil composition. Soil with strong C-H, N-H, and O-H bonds absorbs more light, which is why wet soil or soil with high organic matter looks darker even to the naked eye. Spectral data, especially in the near-infrared, is even more powerful. The reflectance signature of a spectrum can be used to measure carbon, nitrogen and water content of soil, and relate to some soil chemical properties as well. Carbon sequestration in agricultural soils has the potential to reward growers, improve soil quality, and reduce CO_2 emissions. Under a regulated offset-trading program, in order for growers to receive payments for increasing soil carbon, baseline carbon levels would need to be measured. Later, verification would be required in order to show carbon had been added. Yet carbon levels vary widely within most fields. This is where the spectrophotometers come into play by offering a reliable and ample image on the soil carbon concentration changes.

2.4. Custom Made Precision Agriculture Equipment

Since the very development of precision agriculture equipment, it was clear that it would be impossible for a certain manufacturer to produce standard equipment for every conceivable field scenario and conditions. As a result, there are many cases where dedicated hardware is needed in order to achieve the final goal [3].

Data Loggers are a cheap but reliable technical solution that supports the development of wireless field monitoring networks. This type of equipment is usually outfitted with temperature and relative humidity sensors. The equipment typically records value fluctuation in user-predefined parameters.

Weather Stations are powerful tools which try to embed multiple functionality features into a single powerful device. They can measure, calculate and log evapo-transpiration (ET), solar radiation, wind speed/direction, wind chill, dew point, temperature, RH and rainfall. Up to five (5) external sensor channels are available for leaf wetness, soil moisture or other sensors.

Nutrient measurement devices are based on the fact that the current cost of nitrogen fertilizers requires growers to make well educated and accurate decisions regarding when and how much nitrogen is needed. Immediate in-field testing determines how much nitrate is already present, minimizing the possibility of wasted fertilizer.

Other custom precision agriculture devices are *UV meters, Light meters, Digital Wind/Temperature Meters, External Soil Temperature Meters, Infrared Crop Temperature Meter, Plant Growth Stations, Weather Trackers, Frost Alert Devices, Temperature Alarms, Plant Disease Stations, Digital Handheld Refractometers, Handheld Potassium and Sodium meters, Soil Stick pH meters, Handheld EC Meters, Waterproof EC meters, Chlorophyll meters, Root Zone Soil Moisture Probes, Irrometer Strain gauges, Soil Compaction meters, Soil Sampler Probes, Tough Soil Thermometers etc.* These are relatively small sized devices which have various roles in precision agriculture farming. They are consistent with custom precision agriculture applications. One should know that these are just a few examples of such devices, and that as the needs of modern farmers change, so do the devices and the technology behind them.

3. From GIS to SIGAA

GIS or Geographical Information System defines a class of embedded software components which are used in a typical precision agriculture mapping system. As the technology advances grew in size and importance, it was clear that it wouldn't suffice to create one GIS class type software for every practical application. Therefore, the new GIS software developer tools are very prone to offer script writing and self configuring tools. The end user now has the possibility to write limited size and limited functionality scripts, which are specific to the user's needs. By using the newly developed script, the end user is able to add new functionalities to his specific dedicated software.

Basically, a GIS based software component can be regarded as a high fidelity model viewer of a particular soil lot, mainly because it can be configured so that it contains topographical data of that soil lot, but it can be programmed to store and manage data about the physical and chemical properties of the soil. Furthermore, real time GPS data can be managed by GIS systems. At any given point in the field, the operator of the large precision agriculture equipment, which embeds this GIS, can verify the exact position of the equipment within the boundaries of the allotted soil. As the equipment operator's position changes, data from the equipment's sensors is being related to the GIS map, while also being correlated to the GPS reported position.

All concepts of Precision Agriculture are established on the collection and management of variable cropland information. As the tool of collecting, managing and analyzing spatial data, GIS is the key technology of integrated Precision Agriculture system. As a result, there have been attempts to merge the GIS software components within different concepts, even to the handling of data from wireless weather sensors [2], as presented in Figure 1.

A suitable way to enhance the existing systems and technologies would be to accurately predict which would be the most suitable crop to be planted on a particular field, for a maximum yield. The development of a new mechatronic system capable of such a task would be most important and efficient for farmers interested in high crop yields. The prediction accuracy of such a system would entirely rely on the accuracy of field data collecting and processing.

This system is developed within a Doctoral Thesis carried on at *Transilvania* University of Braşov, Department of Advanced

Mechatronic Systems, and will be further referred to as SIGAA (Advanced Agricultural Geographical Information System). It is this system's primary task to compress all previously available soil fertility maps into a comprehensive "timeline". This should provide the farmer with an efficient way to track down the fertility changes that took place in his lot, along the past years. SIGAA correlates this data with specific chemical properties analysis of the lot in question, and based on statistical algorithms plus fuzzy logic based operations it is possible to make pertinent predictions on the crop that would most likely have the largest yield on that specific soil lot. This decision making process takes into account the variables like plant specific nutrient quantities, sun exposure and intensity, soil humidity etc.

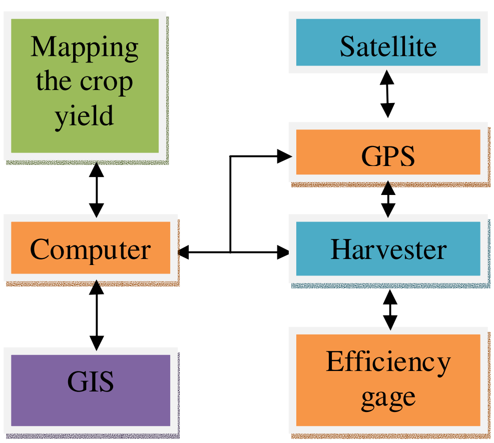

Fig 1. *The general architecture of the IT systems for GPS harvesters*

Since a high crop yield does not always guarantee profit, or even the coverage of the crop investment costs [4], it is an imperative decision of including a way to correlate the crop yield to the possible profit margins. By including an internet connection to the SIGAA, it is possible for the system to access the most important national or international ware stock exchange markets and to offer the farmer a complete picture of economical choices. It can easily be referred to a decision support system. SIGAA offers complete transparency of choices which balances crop yield and profit margins. The opportunity for technologic transfer for such a system is quite large, since the precision agriculture technology has begun to grow in its own niche.

4. Compared Analysis and Conclusion

For the purpose of having a well documented image of the benefits SIGAA would has over classic GIS software, it has been imperative to compare SIGAA against two of the most popular open source GIS class type programs. It was compared against GRASS 6.4.0RC6 with MSYS and against MapWindow 4.8.1. The criteria used are the following:

P - precision degree of the model viewer;

D - development opportunities by script writing and add-on merger,

E - ease of use;

C - connectivity to the internet and ability to retrieve data;

G - GPS direct link availability.

Every criterion has been compared and graded in relativity to other criteria as presented in Table 1.

Table 1

Correlations giving the relative importance ratio

	P	D	E	C	G	Pts.	Lvl.	Ratio
P	1/2	1/2	0	0	0	1	5	0.25
D	1/2	1/2	1	0	0	2	3	1.1
E	1	0	1/2	0	0	1.5	4	0.63
C	1	1	1	½	0	3.5	2	2.71
G	1	1	1	1	1/2	4.5	1	5

As it may be observed in Table 2 and Table 3, the compared analysis has clearly stated that by using the criteria and the importance ratios intended, the SIGAA system can offer significant benefits compared to the systems currently available.

Table 2

Table with Grades relative to each software

Criterion	GRASS	MapV.	SIGAA
	N_i	N_i	N_i
P	9	6	6
D	8	9	7
E	5	10	10
C	2	7	10
G	3	6	8

Table 3

Relative grade multiplied by the relative importance ratio; r = ratio, c = criteria

		Grass		MapV.		SIGAA	
c	r	N_i	$N_i^* r$	N_i	$N_i^* r$	N_i	$N_i^* r$
P	0.25	9	2.25	6	1.5	6	1.5
D	1.1	8	8.8	9	9.9	7	7.7
E	0.63	5	3.15	10	6.3	10	6.3
C	2.71	2	5.42	7	18.9	10	27.1
G	5	3	15	6	30	8	40
Total		34.62		66.67		82.60	

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