Sustainable Agriculture using an Intelligent Mechatronic System

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***Abstract*- The goal of the Project group created by U.P.M. in collaboration with Foreign Universities, Research Institutions and Companies is the development of an intelligent mechatronic system for the use of precision and sustainable agriculture. The project as a whole includes the following components: photographing and decoding of the soil surface; fertility determination and formation of the fertility map; generation of the controlling signal for mechatronic dosing device; intelligent dosing of fertilizers; simulation, prototype and testing; human-machine interaction and training preparation.**

I. Introduction

Modern agriculture in developed countries can not be imagined without intelligent machines and intensive usage of chemical fertilizers. This is necessary in order to keep good fertility level of the soil where it is used intensively. However, the other side of the coin is the overdosing of fertilizers which threatens food safety and deteriorates the quality of soil. This is because the farmers are not always aware of the detailed updated soil content analysis. Also the existing fertilizing machines do not allow farmers to adjust the dosing of fertilizers "on-line" depending on the actual chemical contents of each specific part of the field. Current conception of agricultural soil management in most of the countries in the world is based on the "equality" principle, which means the equal crop management in various weather conditions, different soil state etc. The widely used technologies of non-adaptive soil fertilising which undoubtedly leads to the imbalance of agro-systems, especially in the sense of ecology and food quality.

Meanwhile, it was determined that there has been a considerable decrease in the effectiveness of the non-adaptive fertilising in the case of the constantly changing weather conditions, and, hence, increase of the environmental pollution, especially pollution of soil and underground waters with agrochemicals in many countries with a developed agriculture industry.

Implementation of the conception of an adaptive intensification of the agriculture production in the form of differential fertilising in real-time mode can only be realised based on information technologies, using the latest achievements in the field of Control Theory, Computer Science, Decision Theory, Robotics and Mechatronics. It is applicable in countries-participants of the Project as well as in all other countries with highly intensive agricultural sector and serious concerns over the environment and food safety.

The proposed theme is studied by various research groups throughout the world. There exist some analogous research in USA, Germany, Russia and UK. The distinction of this project is the design of a complete functioning prototype system, which would integrate the latest research achievement from various disciplines and use end-products of different branches of the industry to improvise adaptive fertilization using satellite images and GPS

II. State of the Art and Objectives

One basic principle of the sustainable agriculture is the management of the variability. This variability can be natural (topographic, edaphic, etc.), or inducted (fertilization, harvest rotation, etc.) or finally combination of both.

At present, we dispose of multiple tools, so as GPS and its applications to locating, driving, sowing, harvesting, etc.

Although the use of satellite in aerial photos is well known and it is applied to determine the harvest state of the crops or to dozen the fertilization it is not yet well developed

Even though we find different software tools in the market for data analysis, which are more user-friendly it is necessary to develop the software further so that that critical information could be extracted from the satellite or aerial photos permitting us to obtain the optimal answer in relation to the fertility map providing inputs for auto-driving, and dozing of fertilizer.

The past five years have seen computer vision techniques applied to UK agriculture, based on UK government and industry funded research [1]. Most machines have been sold for inter-row cultivation [2], though a significant number also include banded application of agrochemicals. Research in the UK and elsewhere has continued to make progress with more challenging applications including following multiple bouts [3], intra-row cultivation between crop plants [4] and the spot application of herbicides [5], [6], [7]. To date research concerning spot application has been restricted to low work rate systems. Consequently researchers have concentrated on operation from autonomous robotic platforms in an effort to minimise running costs (patent WO06063314 (A2)). However, issues of capital cost, safety and reliability currently put such systems outside the scope of commercial operation. Furthermore, these systems have not addressed all the issues associated with working under natural lighting or commercial field conditions.

Progress has been made to develop application systems for defined situations, in targeting herbicide applications [8], [9] and in controlling spray drift. Little work has been conducted on spot treatments. Studies conducted in the USA [10] showed that the approach was feasible but used techniques that were not relevant to full scale operation at realistic forward speeds.

Studies, developments and techniques have been tested in different areas in different countries, but the results are not satisfactory. Hence, it will be necessary to develop a mechatronic system in the near future, as a tool to sustainable agriculture, suitable and profitable to provide to farmers. The target of the project is to develop such a system (Fig. 1).

The system will work as follows. The photographs of field will be taken by the satellite. Then they will be decoded to provide information on actual state of each part of the field. After that the program for fertilizing the whole field will be generated considering state of soil, weather conditions, type of crop etc. The program will be downloaded to on-board control unit of mechatronic dozing device on the tractor. When the fertilizing process starts the monitoring device will constantly check its position using GPS Galileo system, linking it to fertilizing program and hence regulating the intensity of fertilizer application. This will be carried out by auto-guidance

It is important that the consortium plans to use some components of the system which already exist (e.g. tractor, fertilizing machine, satellite service) or which are to be applicable soon (Galileo positioning system). Both of these components decrease the project cost and make its success more feasible. The integration of already available components improves the commercialization of project results.

III. GENERAL CHARACTERISTICS OF THE SYSTEM

Open modularity -. The project is focused on the development of "trainable" machine vision algorithms and of appropriate machine learning techniques. In order to create such methods we will focus on the following scientific objectives: (a) machine learning methods for processing the complicated data produced by the vision system, (b) methods to deal with multiple, possibly contradictory input by the operators; (c) methods for predicting success or failure of the learning process in early stages of the training process.

Efficiency and dependability - The control will be able to cope with activity of the mechatronic device in dynamic environments, disturbances and partially uncertain components. None of these will affect the efficiency of the mechatronic device and protection of the environment. To this end, Artificial Intelligent techniques will be applied, which are able to cope with changes without degrading the performance of the mechatronic system and with uncertainty embedded in agricultural issues.

Autonomy and flexibility - autonomous planning, targeted navigation, behaving abilities based on the reliable situation interpretation and intuitive usability in direct interaction will be integrated. These issues include: (a) decision making techniques for determining which fruit is suitable for harvesting, (b) the detection of the position of fruit to be harvested using the GPS, (c) optimal planning for fruit-harvesting. A minimum-time task-planning method using evolutionary algorithms will be developed.

Collision Avoidance - The collision avoidance module will flexibly react to fixed obstacles, such as trees and fences, and unforeseen changes of the environment, such as people or animals that move in front of the mechatronic device, based on input from the vision and GPS sensors. Path planning modules and decision-making techniques will be developed allowing the mechatronic device to reliably navigate in cluttered environments.

The device is extremely useful for tasks which could be risky at present to commit human involvement, tasks where access might not be possible without mechatronic support, tasks where such support would significantly enhance the speed and accuracy and avoid significant toxic/radiation/flammable/explosive contamination and other relevant hazardous situations or combinations of hazards. The revolutionary design concept of the system will provide flexible mechatronic technology with functions and features satisfying the expressed desires and priorities of a broad spectrum of potential users under various weather conditions and soil properties.

A higher level of control will be added to close the control chains, feeding back information from added environmental sensory devices. Disparate technologies will be investigated and integrated in end-user industrial scenarios: topics include control theory, video sensors, visual processing algorithms, sensors fusion, communication networks and real time operating systems

IV. THE CONSORTIUM

To carry out the project a consortium has been created. This is shown in the Table 1.

This consortium consists of multidisciplinary team of partners from EC and Third Countries, encouraging ICPC participation. All of them will be assigned for their specific expertise in the required innovation fields addressed in the proposal. Therefore, the proposal requires the Co-ordination of these different expertise and competencies: autonomous mobile robot, robotic navigation and control, data fusion, cognition systems, pattern recognition, sensor and electronics, embedded system, intelligent systems, Neural Networks, Multifractal Analysis, Pedologic and agriculture techniques Decision Theory, software development, wireless communication and exploitation skills.

V. METHODOLOGY AND ASSOCIATED WORK PLAN

The project is integrated by 9 workpackage groups (WPGS), each of them led to a academic or industrial member. They will be responsible for overseeing day-to-day task management and in charge of that particular work package (WP).

In the Table 2 are summarized the WP and the WP leaders, and then the main features of WP 1 to 7 is described.

1. Photographing of the soil surface

Technology for mapping surface soil properties and estimating soil properties has been significantly advanced by developments of various types of 8 new space borne, airborne and ground-based sensor technologies.

TABLE I
CONSORTIUM PARTICIPANTS LIST

N°	Participant	Country
1	Technical University of Madrid – UPM	Spain
2	Cardiff University – CU	United Kingdom
3	Moscow State Technological University - STK	Russian Federation
4	Parco Scientifico e Tecnologico della Sicilia S.c.p.a.- PSPIT	Italy
5	Grupo INLANDGEO - GI	Spain
6	Derby University - DU	United Kingdom
7	Patras Science Park S.A. – PSP	Greece
8	Tekniker - TEK	Spain
9	Innora Ltd. - INN	Greece
10	Sparky Agromashina Ruse - SAR	Bulgaria
11	Bodegas Faustino - BF	Spain
12	Ingeniero Guillermo Bonamico – IGB	Argentina
13	Instituto Nacional de Tecnologia Agropecuaria - INTA	Argentina
14	Russian end-user	Russian Federation

Recently sufficient amount of high precision data have become available in mapping properties of soils, for example, hyperspectral and multispectral remote sensing images with multiple spatial resolutions are available for mapping soil properties including humidity, surface roughness, surface crusting, and water storage [11].

It is necessary, then, a method useful for mapping these types of properties by separating the background values with local singularity removed for estimation of soil properties from anomalous values showing local singularity for detection of local variability of soil properties.

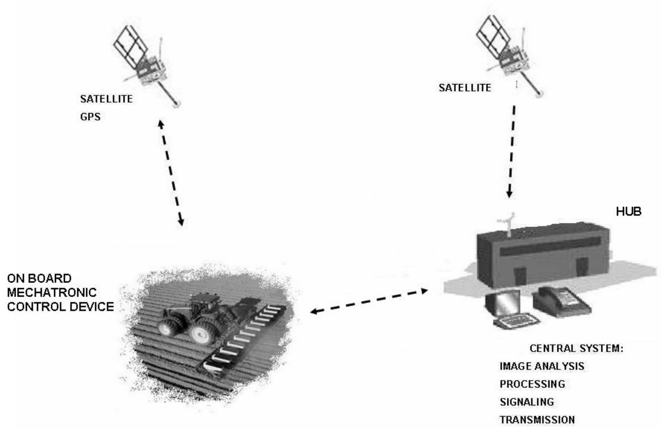

Fig. 1. Basic Scheme of differential soil fertilizing

The objective of this WP is to obtain the best photos taking into account different variables: suitability for the project, cost, availability, periodicity, etc.

2. Decoding of the soil surface photos

Soil properties are different from location to location and understanding the spatial variability has important applications in agriculture, environmental sciences, hydrology, and earth sciences.

TABLE II
WORK PACKAGE LIST

WP N°	Participant Organization Name	*WP leader*
1	**Photographing of the soil surface**	*UPM*
2	**Decoding of the soil surface photos**	*UPM*
3	**Fertility determination and formation of the fertility map**	*CU*
4	**Generation of the controlling signal for mechatronic dosing device**	*PSP*
5	**Intelligent dosing of fertilizers**	*STK*
6	**Simulation, prototype and testing**	*CU*
7	**Human-machine interaction and training preparation**	*STK*
8	**Further research, dissemination of results and commercialization**	*PSP*
9	**Project management and coordination**	*UPM*

Studies on spatial variability of soil properties have in most cases indicated considerable variation, especially for soil hydraulic properties. In general, spatial variability of soil properties represents the interactions among soil physical, chemical, and biological processes that operate on a wide range of spatial and temporal scales. Some of these processes vary frequently in space and are referred to as high-frequency (small-scale) processes, while other processes vary slowly, and are called low-frequency (large scale) processes. The scale of these processes extends over spatial scales of a few centimetres to tens of kilometres and over spatial scales from seconds to decades.

Elucidation of the scales of these processes is essential for understanding and predicting soil hydrological, biological, and chemical processes.

We will develop a technique that combines scaling property for data interpolation and for downscaling image processing. The inputs taken will be point data and an image. Then the values should be separated into a background component for estimation purposes and an anomalous component of singularity for multi-scale high-pass filtering purposes.

Spectral analysis transform values from the spatial domain to frequency domain and then partitions the total variation (or variance) of sample values into spatial frequency scales, thus identifying the dominant spatial scales of the variations; and wavelet analysis partitions the sample variation into positions (or locations) as well as frequencies. Geostatistical, spectral, and wavelet analyses deal primarily with variance and covariance. In the following, we limit our scope to the methodologies of the spectral and wavelet analysis applied in soil science. We will review the methodologies of spectral and wavelet analyses applied in soil science, many of them based on Kumar and Fouloula-Georgiou and Torrence and Compo books.

The objectives of this WP are:

- To develop a method to group the equal fertility zones from the satellite surface photos
- To optimize this method in order to use minimum number and quality of photos reducing the cost.
- To obtain a robust program that provides precise information to correct fertilization and is amicable with the access and the delivery of data to the system.

3. Fertility determination and formation of the fertility map

This workpackage is required to provide the on-site out-of-doors research of the equal fertility soil zones in order to provide the fertility map of the field. This research should be simultaneously simple and accurate. Based on the soil sample data a fertility map should be created for the whole field. Afterwards, the fertilising programme should be generated, in which every part of the field will be corresponded with the fertilising intensity.

The objectives of this WP are:

- To design specialised equipment with automatic probing, testing of soil samples and storing of soil quality results.
- To develop a robust and inexpensive method to test the soil quality from the soil samples taken from the field.
- To optimise this method in order to use minimum number of soil sample tests to achieve reliable results whereby reducing the cost.
- To create fertility map and look-up table with the surface area grid and their corresponding soil quality index.
- To formulate a method to group the equal fertility zones using the fertility map with the look-up table.
- To identify any obvious and hidden fertility zone patterns using data mining and machine learning techniques.
- To predict the soil quality index for the corresponding surface area grid.
- To generate a soil index and fertility profile for each of the surface area grid.

4. Generation of the controlling signal for mechatronic device

The device is an intelligent mechatronic system capable of achieving given goals under conditions of uncertainty that change dynamically due to the weather. A set of sensors will be installed including GPS transmitter-receiver, sensors on condition of environment and of machine itself considering humidity, surface roughness, surface crusting, and water storage. In contrast to existing systems, which are, by definition, pre-programmed to deliver given behaviour and are therefore predictable, our device may arrive at specified goals in a non-deterministic manner.

The main objectives are to achieve the basic knowledge of fertilizers and sensory-motor control of the mechatronic devices and to exploit this knowledge to develop a new kind of a mechatronic device which will overcome some of the drawbacks of current systems. This new mechatronic device will:

- be adaptive to various weather conditions, soil properties, water storage, geological characteristics
- be fed with signals taken from sensors (space borne, airborne and ground-based)
- be controlled by processing the signals coming from the central system
- give output of the appropriate dose of fertilizers

5. Intelligent dosing of fertilizers

One of those devices will be an intelligent mechatronic devive dosing of fertilizers specific to the proposed system. This device will be extensively tested in simulation experiments to verify its effectiveness before the final experiments. To achieve the optimised design, we will: develop signal-processing algorithms in order to synthesize the information according to the porpoise of the chemical application, develop the algorithms for the implementation of the dosing-device control during the different geological characteristics, define the algorithms to code the sensory information, of these algorithms and finally optimise and integrate these algorithms.

For that the objectives of this WP are:

- To model the fertilizer dispenser
- To optimize the fertilizer dispenser
- To design the intelligent mechatronic dosing system

6. Team of robots

The architecture of the proposed system will permit the coordination of heterogeneous robotic units, each of them dedicated to one or more specific tasks. This modularity will allow quick and easy reconfiguration of the system according to different scenarios and needs, such as exploration, sensing, monitoring, and collection of soil and environmental samples, etc. The robotic units will possess adaptation and cognitive capabilities in order to be able to operate reliably in open-air scenarios and free human operators from the control of low-level navigation and sensing tasks such as path planning, obstacle avoidance, etc.

The robots will require sensing, cognition and adaptation capability in order to function in an *autonomous* fashion. This will require certain degree of sensor fusion, self learning using neural networks, and continuous tracking and monitoring of the individual robots. The individual robot behaviour will be established according to the catalogue of activities which need to be performed. Using appropriate optimisation techniques, and in particular the swarm-based "bees algorithm" the optimal path and task schedule will be established given the location of the robot and the tasks it has to perform. Further, the individual robots will be enabled to co-operate with other robots and work in a team by employing the framework built on information sharing and swarm intelligence. Finally, *the safety issues on the robot autonomy* will be scrutinised and emergency stop procedures will be included through multi-modal interfaces.

7. Simulation prototype and testing

In order to visualise the concept and the operation of the overall system a simulation environment will be developed. Using this environment the intelligent mechatronic dosing system together with a team of robots will be simulated to ensure smooth operation. Before the prototype system is produced and assembled the system's functionality, stability and compatibility of all the elements will be analysed using the simulation environment. Later the individual robots will be built according to the specifications and behaviour outlined and successfully simulated. All necessary hardware and software components will be integrated to create the actual prototype of the overall system. Further, some test procedures will be created to benchmark the operation and behaviour of the proposed system in order to examine its strengths and weaknesses.

A great deal of functional flexibility and versatility will be derived from the use of software and the integration of the system into real environments. When the system has been developed and tested, end-users will have the opportunity to evaluate it in real-world situations. Particular attention will be reserved to the validation of final product and the exploitation of the results of the project in order to obtain a usable device. The proposed system will be tested in three different open-air scenarios that are developed in coordination with end-users in the consortium. The three scenarios will pose different locomotion and sensing challenges, and will imply the use of different robot-mounted modules. In all the cases, different tests will be performed in order to validate the capability as an integrated system on managing different crops on different soil types, in different climate zones and under different weather conditions.

8. Human-machine interaction and training preparation

This working package will be devoted to human-machine interaction of end-users and training of end-users to use the developed system. It is necessary to consider that the typical end-user (agriculture farmers) may not be familiar with details of how this system works and with scientific principles and methods used within this system.

However the end-user should be able to use system properly in order to utilise all the efficiency of it. This would also affect the structure of overall system and especially its components involving human-machine interaction and interfaces.

Special training courses should be developed considering the current education trends of European Union (Bologna process etc.).

The objectives of this WP are:

- To provide a friendly human-machine interface for end user (agriculture farmer)
- To prepare suitable operation manuals for end user and training courses

VI. IMPLEMENTATION: MANAGEMENT STRUCTURE AND PROCEDURES

The project will be managed through a three level structure. At the top of the structure, there is a Steering Committee (SC). SC is the decision-making and arbitration body concerned with policy and strategy.

The Executive Board (EB) forms the second tier of management. It has the power delegated to it by GC to implement the policy and strategy decisions. The day-to-day management of individual Workpackage Groups (WPGs) is carried out by Workpackage Leaders (WPLs) constituting the third tier. WPLs are empowered to make operational decisions within constraints agreed by EB.

To ensure that operates efficiently, the Coordinator will appoint a full-time Project Manager to perform all day-to-day management including activities such as coordination, quality assurance, financial administration, and internal and external communications. The Project Manager (PM) will be responsible to the Project Director (PD) representing the Co-ordinator. Furthermore, the Coordinator will deploy two of its specialist project management and administration units to support it.

VI.1.Steering Committee (SC):

The SC is the highest-level managers of all the partner organisations. It will meet every six months. The Project Director shall assume the chair of its meetings. The SC approves and is responsible for: (1) Political and strategic orientation of the project; (2) Project Work Plan and Plan for Dissemination and Exploitation of the Knowledge; (3)

Consortium's budget and task allocation between partners; (4) Exclusion of a contractor, or inclusion of a new partner; (5) Approval of proposals by the EB.

VI.2. Executive Board (EB):

The EB consists of the Project Director, Project Manager and Workpackage Group Leaders. It will meet every three months. The Project Director shall assume the chair of its meetings. The EB is responsible for: (1) Monitoring the progress of workpackages against the Work Plan; (2) Ensuring the coordination of the project activities; (3) Implementing the scientific orientations decided by the GC; (4) Reviewing Intellectual Property and Quality issues and reports proposed by Project Manager; (5) Approving agenda for consortium meetings proposed by the Project Manager; (6) Proposing solutions to resolve any problems arising from WPGs; (7) Implementing the procedure for inclusion of a new partner or exclusion of a contractor; and (8) Proposing modification of budget and task allocation. The Ethics

Advisory Panel will advise the EB.

VI.3. Workpackage Groups (WPGS):

The WPG consists of the technical personnel appointed to a specific workpackage (WP) and will be led by the WP Leader (WPL). WPGs will meet during the GC meetings. They will be responsible for overseeing day-to-day task management and in charge of that particular WP. The actions within every WP are also carefully planned and verified using the same strategy as that used by the EB. WPLs will control progress by monitoring and assessing it through technical reports developed by the participants and task leaders. WPLs can make proposals on the allocation of tasks, financial needs and allocation among the Contractors, the need to bring in new contractors, need for subcontractors for the establishment and the fulfillment of the Work Plan. They will draft and validate Project Deliverables on the workpackage to be submitted to the Commission and will identify Contractors' presenting financial or technical risks within the concerned workpackage and inform the coordinator. In the same way, WPLs will inform the coordinator of any other difficulty arising in connection with the conduct of the tasks. WPLs will ensure the scientific monitoring and coordination of the workpackages as well as ensure their implementation.

VI.4. Project Coordinator:

The UPM has an international track record of successfully managing large research programmes, multinational collaborative projects, networks of excellence and technology transfer initiatives of a scale similar

The UPM will support the technical management aspects of UPM, as Co-ordinator, has full responsibility for achieving the contracted results. The University will ensure that the strategies identified at Board level are developed at the Group level.

VII. Impact

The project provides a strong motivation and the capabilities to effectively integrate available state-of-the-art technology through a multidisciplinary team which builds on and integrates progress in a number of underpinning technologies and disciplines, namely context aware sensors, sensor data collection and fusion, automated reasoning techniques and learning and human-computer interaction, robotic and mechatronic

The involved partners are high level academic institutions, two research institutes are strongly projected towards the industry; there are four industries that provide the industrial vision and exploitation capabilities. These partners will facilitate technology transfer by promoting market level initiatives, thus strengthening the exploitation potential. Finally there is an organism that provides the need specific background on sustainable agriculture, allowing a user centred approach and ensuring that the results really answer to farmers needs. A quite exhaustive state of the art research has been achieved and international (at both European and global levels) and national research activities sharing common points with *this project* have been identified and analyzed. The consortium intends to follow up the ongoing research of these projects. *The project* commits itself to collaborate with other projects under the same Strategic Objective.

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