ICT-AGRI Call 1 Final Project Report

Acronym: 3D-MOSAIC

Project duration: 01.05.2011 – 30.04.2013

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Summary report

3D-MOSAIC targets zone or tree individual production measures that shall trim down the environmental footprint of food production through enhanced resource efficiency. The application of ICT considering plant monitoring and spatial evaluation tools has a high potential to cope with this problem. 3D-MOSAIC captured a horizontal approach bringing together work groups with synergistic multidisciplinary expertise, facilities, and infrastructure. Experiments were carried out on economically important fruit trees (citrus and plum). Tree monitoring was carried out by means of manual rating, laboratory analyses, and automated 3D-MOSAIC sensors.

For the automated plant readings, an autonomous platform was adapted to carry and control sensors (vision systems) and collect data from low-cost fruit sensors by wireless sensor networks in the orchard. As an important plant growth indicator, the leaf area was analyzed by algorithms for fast image analyses comparing 2D and 3D camera readings (3 RGB 1280x920 images with 60% of overlap (Bumblebee XB3), 2 Grasshopper 2 1600x1200 intensity (8bit) NIR Images) as well as LiDAR systems.
Emerging sensors, capturing thermal imaging, NDVI and hyperspectral readings, were tested for measuring spatial canopy variation. Vis/NIR spectroscopy and multispectral backscattering imaging were employed on subsamples for approaching the fruit quality. Novel 3D-MOSAIC sensors for fruit analyses in-situ were developed, and advanced by means of robust calibrations based on physical models for photon transport in plum and citrus, as well as pip fruit and berries for comparison.

In field trials - that were undertaken in the Mediterranean on *Citrus paradisii* and in temperate climatic region on *Prunus domestica* - interactions of soil and yield parameters (vegetative and generative growth, tree water status, yield, and fruit quality) were studied. The data outcome is a 3D grid, in which plant, soil, and climate data are considered. Some of the data were already coming from novel sensors or new approaches in data processing, providing the necessary prerequisites for spatially resolved information. The numerous data sets, structured in GIS, were evaluated by means of a spatial decision support system. Getis-Ord Gi* statistic was employed for defining hot-spot and management zones based on the evaluation of the autocorrelation degree considering yield parameters and soil data.

Consistent with findings in precision agriculture of arable crops, correlation was found between soil electrical conductivity and yield parameters. In the (short) two project years, we were able to achieve a comprehensive view on precision fruticulture, while applying and learning in synergistic work groups on specific targets (from the robot and WSN, through sensor robustness and emerging technologies, to the spatial G* statistics for delineation of management zones).
We expect the new movement for building decision making tools based on spatial plant readings have substantial impact on managers of orchards. From a FARMER perspective it was stated that "farming with sensors is so much easier". By the bringing facilities together, the project outcome benefits the economically and socially necessary automation of agricultural processes and supports the PRECISION FRUTICULTURE concept.

Keywords: autonomous platform, backscattering imaging, bumblebee, citrus, decision support system, fruit quality, fruit sensor, hot-spot, management zones, photon transport, plum, precision fruticulture, soil electrical conductivity, spatial analysis, yield

Description of activities and final results

The 3D-MOSAIC project was aimed at the set-up of an advanced concept for precision fruticulture based on ICT solutions. The project was organized in work packages (WP1-6) (figure 1) and captured four objectives (O1-4).

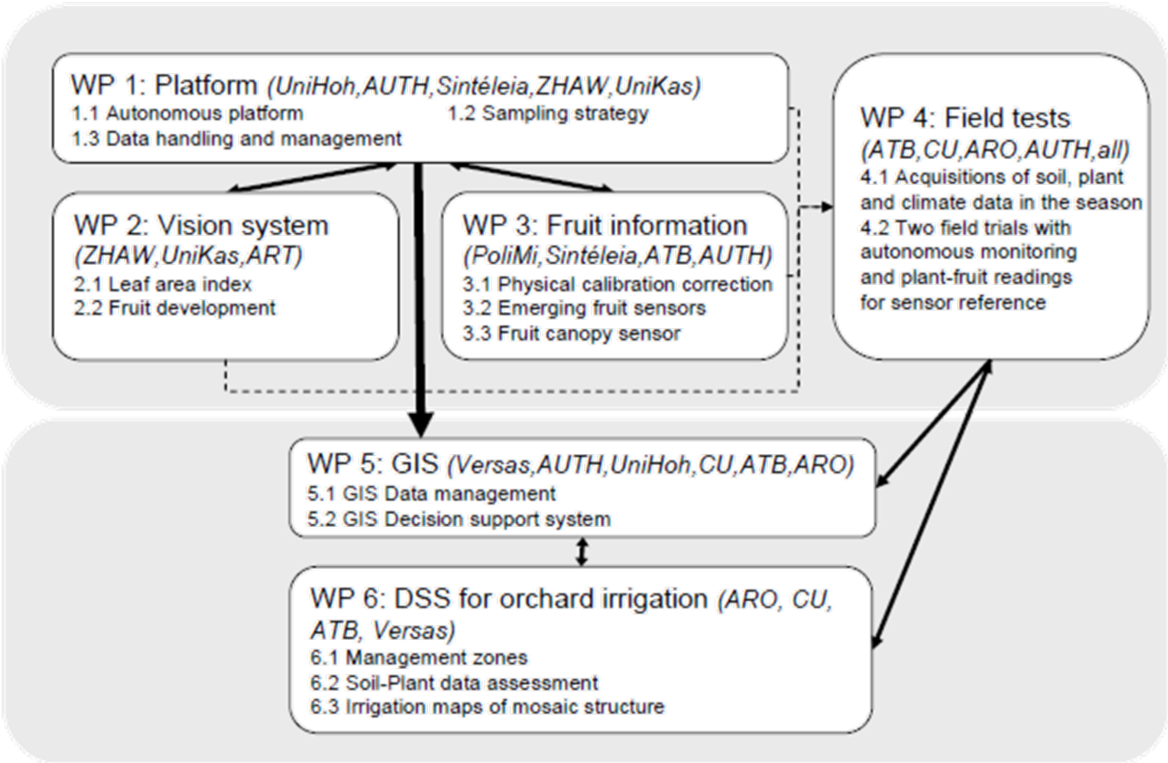

Fig. 1: Overview on 3D-MOSAIC work packages as planned. During the project time the new subtask 1.4 “Navigation” was introduced, while 1.2 went under the responsibility of AUTH.

O1. **Mobile geo-referenced data acquisition in an orchard by a robotic platform**

The platform and navigation software for autonomous operation was achieved. A protocol for communication and software implementing the protocol was developed. Based on the developed software the navigation sensors were able to control the platform and thereby making the autonomous data acquisition possible. For the second field trial, the autonomous platform and sensors were operational and capable of collection data from the trees. The three canopy sensors, IR cameras, LIDAR and Bumblebee XB3 stereo camera were successfully integrated and connected with the central control unit of the robot.
The platform and software are ready in a prototype stage and ready to use for scientific purpose. Compensation of platform vibrations and movements would allow even more reliable results of the LIDAR system. The solid but stiff construction altered the data significantly and requires calibration of the IMU to reconstruct the 3-D point cloud. Still stereo images are providing results which are expected. The solution realized in the project has scientific value; the sensor technology has the potential to be used in practice but needs further development for this aim.

The fruit sensors (manual and stationary readings in the trees) can be integrated in the data acquisition by means of wireless sensor network. Radio propagation within the plum

orchard of field trial 2 was investigated using ZigBee devices operating within the 2.4 GHz band. Measurements were performed to estimate the power attenuation due to the presence of the tree structures and their foliage. Radio path loss, with and without leaves, revealed that at antennas heights close to the tree tops the path loss was not affected significantly by the presence of leaves, mainly because of diffraction from the tree canopy – air interface, which provided an additional propagation mode. At antenna heights where foliage takes up a significant portion of the propagation path the attenuation was increased in the presence of leaves. Still, at 2.4 GHz this effect was not severe because the corresponding wavelength is greater than the average leaf size of the plum tree. An approach was carried out to characterize empirical data by means of established vegetation-attenuation models. The most accurate model for the particular orchard layout was the parametric exponential decay model using parameters best fitted to the measurements, whereas the second-best was the standard Weissberg exponential decay model, which doesn't require any parameter fitting. Also, several standard exponential decay models, which have been developed for forest environments can be used as 'conservative' upper bounds of path loss, at least for the particular orchard. These models can also be used for the prediction of range between wireless sensor network nodes in orchards, since range can be defined as the distance over which the received power drops below the receiver's known sensitivity.
Additionally, radio signal attenuation data were measured in a cherry orchard during the second field trial with leaves. Cherry tree geometries were digitized and measured again without leaves and used to approximate the orchard geometry in the COMSOL FEM computational platform. Computational modeling of radio propagation was solved and compared to the measured data.
The radio performance data of the two orchards were analysed and compared against theoretical predictions. All calculation spread sheets and software were completed. The results of this deliverable will contribute towards better understanding of radio propagation in orchards (scientific community) and can be used to guide the design of wireless sensor network nodes (companies), and the optimal placement of the nodes, thus improving the robustness and cost of WSN systems for agriculture.

O2. **Monitoring of plant and fruit growth by means of automated sensors** using a multiple sensors and a geo-information system (GIS)

<u>Canopy data</u> were acquired in the first project year manually with LiDAR and 2D IR-camera. The first experimental series aimed at an evaluation and comparison of these methods at a vertical top-down viewing direction of the sensors and was conducted in an experimental orchard of 180 plum (*Prunus domestica*) trees. Image analysis showed a higher vulnerability to the sensor mounting height and tilting movements of the carrier vehicle. Consequently the Pearson correlation between two acquisition cycles of the orchard trees at different mounting heights was higher for the LiDAR (0.975) than for the camera system (0.893). However, on uniform terrain a correlation coefficient between both systems of 0.917 could be achieved. Each of the two techniques was additionally compared with the number of leaves per tree showing similar high correlation with higher values for the camera system. The findings confirm the use of both systems for leaf area estimation, while fruit detection e.g. with watershed algorithms resulted in high measuring uncertainty.

In the second project year the approach was repeated by the d vision systems mounted on the platform, capturing 2D 608 nm LIDAR data, 190 degrees 0.116 degree resolution, is considered as ground truth; and 3 RGB 1280x920 images with 60% of overlap (Bumblebee XB3) 2 Grasshopper 2 1600x1200 intensity (8bit) NIR Image.

The software for complete control of the vision systems and the data acquisition are realized and tested in the field. Off-line processing system with MATLAB and OpenCV is realized to obtain point clouds from the stereo camera XB3 and IR camera pair. The system is fully functional and data processing has achieved stable state (pre-release state). All acquired data was processed with variety of state-of-the-art stereo matching algorithms. 3D image acquisition provides (apparently) no benefit over 2D (although theoretically it should, allowing for a dome shaped recognition of a canopy rather than a block shaped recognition). In both approaches, the estimation of leaf area could be automated, while the fruit detection remains difficult due to similar radiometric and shape properties of leaf and fruits. Automated canopy readings have the potential to create an impact on the future development of close-range sensor systems for classification purposes. Although the performance of the system needs optimization, it has shown that the approach could be used in the near future.
The vision system represents close range multi-spectral sensor system with geo-referencing capabilities (if GNSS-IMU system is mounted). Trees served as geo-references during the data post-processing, but later on also geo-referenced data were used for delineation of management zones.

<u>Fruit sensors:</u> Solid tissue phantoms were prepared with optical properties typical of plant tissue in the visible and near infrared range. The absorption coefficient range is 0-0.49 cm^{-1}, the reduced scattering coefficient range is 5-20 cm^{-1}, and the size is cylindrical (15 cm diameter, 4.5 cm height). The availability of calibrated tissue phantoms with stable and reproducible optical properties is of the utmost importance for performance assessment of any optical sensor based on remittance readings.
Physical models for photon migration in diffusive media are rarely applied in the agricultural field while they found several applications in the biomedical field. The use of physical models will help the design and development of better and more accurate optical sensors based on diffuse reflectance.
The novel multi-path sensor built, was characterized during a collaborative measurement campaign on the set of 32 solid phantoms. The sensor was derived with the peculiar feature of sampling at one of H_2O absorbance wavelength and two path lengths between emitter and receiver, to obtain a simple non-destructive method for analysing the water content of the fruit. The optical filter developed for this device permitted to verify the improvement of selectivity using narrow bands filter. The correlation between sampled data and data coming from laboratory destructive tests are encouraging.
Absorption and reduced scattering spectra in the 540-940 nm spectral range were measured at different fruit development stages on Ruby Red grapefruits harvested during the field trial 1 organized in Adana (Turkey). Due to the thick skin (i.e. albedo and flavedo > 0.5 mm), when using CW optical sensor in the reflectance mode it is necessary to use large source detector distances (i.e. >2 cm) to reach the underlying pulp.
Measurements on apple and plum at different development stages were performed to check whether large changes in the optical properties are occurring during fruit growth and tissue differentiation. The absorption and reduced scattering spectra of apple harvested in the experimental orchard of field trial 2 in Potsdam (Germany) at four dates before commercial harvest showed large changes in the chlorophyll content (as measured by the absorption coefficient around 670 nm) while minor changes were observed in the reduced scattering coefficient. Similar results were found on plum for the absorption coefficient, conversely the reduced scattering coefficient showed much larger variations and a stronger dependence with the wavelength. The use of empirical method assuming that the reduced scattering coefficient is constant during growth can be acceptable in apple but not in plum. In the latter, the perturbations due to scattering variation requires corrections, e.g. by means of time- or spatial-resolved readings.

Emerging sensors were applied in the framework of the field trials and related experiments carried out in bilateral exchanges.

a) Backscattering imaging: The preliminary experiments on backscattering imaging on citrus fruits (field trial 1) resulted in an interesting approach on detecting early decay symptoms in citrus by means of multi-spectral readings of the photon backscattering. Early detection of fungal infections in citrus fruits still remains as one of the major problems in postharvest technology, since diseases caused by fungi can lead to high economic losses for the industry. The potential of laser-light backscattering imaging technique was evaluated for detecting decay after inoculation with the pathogen *Penicillium digitatum*, before the appearance of fruting structures (green mold). Backscattering images of citrus fruits cv. 'Navelate Navel' with and without decay were obtained using diode lasers emitting at wavelengths: 532, 660, 785, 830 and 1060 nm. The backscattered region captured by a camera had radial symmetry with respect to the incident point of the light, being reduced to a one-dimensional profile after radial averaging. The Gaussian-Lorentzian cross product (GL) distribution function described radial profiles with average R^2 values greater or equal to 0.998. The GL parameters at each wavelength were used as input vector for classifying fruit samples using a supervised classifier based on linear discriminant analysis (LDA). Laser wavelengths were ranked in terms of their contribution to the detection of decay. The minimum classification average success rate of 80.39% was obtained using a single wavelength. However, by employing the five laser wavelengths, increased average success rate was found up to 96.08%, with a percentage of well-classified fruit samples greater than 95% for both classes.

Because of novelty of this technique, developed algorithms for processing this type of images are in preliminary stage. Some work went into the investigation of the feasibility of texture-based analysis and coefficients from space-domain analysis to develop better models for predicting mechanical properties (fruit flesh firmness or elastic modulus) of horticultural products. Images of apple and plum were acquired using a backscattering imaging setup capturing 660 nm. After segmenting the backscattering regions of images by variable thresholding technique, they were subjected to texture analyses and space domain techniques in order to extract a number of features. Adaptive neuro-fuzzy inference system models were developed for firmness or elasticity prediction using individual types of feature sets and their combinations as input for prediction model applicable in real-time applications. The maximum value of correlation coefficient in the prediction stage was achieved as 0.887 and 0.790 for apple and plum, respectively.

b) Vis/NIR spectroscopy: The decline of fruit chlorophyll is a valuable indicator of fruit ripeness. Fruit chlorophyll content can be non-destructively estimated by UV/VIS-spectroscopy at fixed wavelengths. However, this approach cannot explain the complex changes in chlorophyll catabolism during fruit ripening. We introduce the apparent peak position of the red band chlorophyll absorbance as a new qualitative spectral indicator. Fruits were analysed at different ripeness stages. The peak position and corresponding intensity values were determined between 650 and 690 nm of non-destructively measured fruit spectra as well as of corresponding spectra of fruit extracts. In the extracts, individual contents of chlorophyll a, chlorophyll b, pheophytin a, and carotenoids were analysed photometrically. Non-destructively measured peak positions shifted unimodal in all three fruit species with significant shifts between fruit ripeness classes of maximal 2.00 ± 0.27 SE nm in tomato, and 0.57 ± 0.11 nm in apple. Peak position in extract spectra was related to varying pigment ratios (Rmax = -0.91), considering individual pigments in the pool. The peak intensities in both spectral readings, non-destructive and fruit extracts, were correlated with absolute chlorophyll contents with Rmax = -0.84 and Rmax = 1.00, respectively. The introduced spectral marker of the apparent peak position of chlorophyll absorption bears the potential for an advanced information gain from non-destructive spectra for the determination of fruit ripeness.

c) In the field trial 2, additionally, three imaging methods were applied: *hyperspectral readings, NDVI assessment, thermal imaging*. The data have been acquired, but needs further processing.

O3. **Verification by field tests**

The field trial 1 with all partners was carried out at the experimental citrus orchard (207 trees used in the field trial) located in Adana (Turkey). The land area is about 1100 ha in operation for field agriculture. During the entire project, the soil, crop and climate data were observed and saved. In addition, the physical and chemical properties of soil profile were determined throughout the root zone of trees. Evapotranspiration of trees were determined by water balance and microclimatic methods: Bowen-Ratio-Energy-Balance (BREB), Eddy Correlation Bowen Ratio Energy Balance (BREB) and Eddy Correlation (EC) systems were used to determine the actual crop water consumption through micrometeorological methods. In the experiment, trees were irrigated with drip irrigation method. The amount of irrigation water applied to the experiment is calculated according to the free open water surface evaporation. Irrigations were initiated when the available soil water level in the root zone falls to, i.e., 50%. Irrigation is repeated at the two weeks interval and ended at the beginning of the rainfall period. Soil and plant measurements were carried out for field trial 1 and maintained over the entire project period. The measurements captured: climatic data, soil moisture measurements, calibration of neutron scattering method using the gravimetric results, irrigation water amount were recorded (continuously), measurement of fruit perimeters, yield (kg/tree),
Soil mapping was carried out with two methods (soil electrical conductivity and magnetic resonance) before and during the field trial.
According to 3D-MOSAIC *milestone 1*, but with a delay of approx. 6 weeks, data from the orchard were transferred to GIS and preliminary results were communicated in the midterm meeting.

In the third half-year of the 2-year project, the field trial 2 was scheduled for all project partners. The experimental orchard located in Potsdam (Germany), was established in 2009 on a hill and consists of six rows with a total of 180 plum trees (*Prunus domestica*). The cultivar has been 'Tophit plus' that was used in the experiment, while 24 pollinator trees of cultivar 'Jojo' were mostly excluded from the data sets.
The tree distance is in x-direction (between rows) = 5 m and in y (within rows) = 4 m. Soil ranges from sandy to loamy sand. The precipitation rate = 458 mm per year and average year temperature = 11 °C. We got the weather data from an automated weather station near the orchard and the chemical soil information from soil analyses within the project.
Soil electrical conductivity (ECa) was mapped in 2011, 2012, and 2013 with 1 m resolution in various soil depths. All trees were manually rated considering vegetative an degenerative growth (e.g.: flower set, fruit set, fruit drop, number of leaves, number of yellow leaves, trunk circumference). Tree performance and water status were recorded (yield, leaf turgor, leaf water potential on all trees, and gas exchange diurnal courses on a subsample). Fruit quality (SSC, acidity, size, fresh mass, dry mass, mechanical properties) was analysed in the laboratory.
According to 3D-MOSAIC *milestone 2*, the automated orchard monitoring was carried out in field trial 2 and data were transferred to GIS by month 20. Preliminary management

zones based on soil ECa were communicated to partners already during the midterm meeting.

Apparent soil electrical resistance data in both Adana and Potsdam have acted as surrogates for a possible number of soil-based properties (> 50 cm depth showing very little spatial differences, but < 50 cm depth showing small scale spatial difference), while laboratory soil analysis (and repeated ECa measurements) assisted in our understanding of spatial ECa differences. Links between ECa and plant yield parameters (see O4) imply benefits of monitoring for such a soil property, even if the bases for spatial variations are not identified. In the classical data analysis done so far, e.g. plum trees were subjected to manual rating, fruit quality analyses, and classified according to the soil apparent ECa in three soil depths (topsoil, root zone, subsoil). The ECa pattern were stable in two years ($R = 0.88$) pointing to small scale, but relatively low soil variability. The ECa in the root zone and crop growth were correlated, with enhanced significance when considering older trees. However, in our study the elevation (slope = 3.15°) of the terrain and ECa of topsoil had similar or higher impact on the yield and fruit quality. Such finding is particularly interesting for orchards that are frequently located on hillside. The ECa in the topsoil and elevation were correlated with the fruit set at $R = 0.17$ ($p = 0.01$) and -0.45 ($p = 0.13$), quantity of fruits/tree at 0.18 ($p = 0.006$) and -0.45 ($p = 0.025$), the yield in kg/tree at $R = -0.34$ ($p = 0.128$) and $R = 0.16$ (n.s.), respectively. Consequently, based on the correlation and ANOVA, site-specific management appears reasonable.

O4. Derivation of **management maps on a tree-level** based on actual data of soil and plant

The systems requirement specification of GIS was discussed with all partners during the kick-of meeting and subsequent communications. GIS platform has been linked to Google Earth and documented describing the requirements for all aspects of the solution that comprises the 3D-MOSAIC ICT concept. The document is broken into several sections, as follows: technical architecture overview, GIS data base, web service interaction for data acquisition, operations & management capabilities, dashboard features management zones.
The system architecture specification was developed and explained to all the partners in the Berlin meetings. The sDSS was developed and discussed in the field trial meetings. Feedback of the partners was received in order to improve the system. The operational GIS data management platform can be accessed by partners. The GIS/sDSS platform is a tool for growers, agronomist and industry to perform GIS view of data and analysis of the information with the sDSS.
All reference data from the field trial 1 and 2 were implemented in the GIS. Data that were subjected to postprocessing have been stored by the responsible partner, while the results were transmitted to all partners. Also, LiDAR and thermal imaging readings (subject to post-processing) were geo-referenced.

Management zones partition agricultural fields into sub-units which exhibit homogeneity in yield-defining environmental or plant parameters. Spatial clustering methods, based on spatial statistics, include location of objects and spatial relationships and account for spatial heterogeneity. However, existing clustering methods have been developed mainly for arable crops and not for individual trees in orchards. For the field trial 1, a section of 207 Rio Red grapefruit trees was monitored in 2011-2012. A set of spatial statistical methods including, in particular, the Getis-Ord Gi* statistic (Gi*) was employed for defining management zones. The Gi* statistic evaluates the degree of spatial

autocorrelation over a study area on a point-based scale by indicating the degree to which each feature is surrounded by features with similarly high or low values within a specified distance. Statistically significant spatial clusters were used for delineating management zones. The method was tested regarding apparent electrical conductivity of the soil (ECa) and tree trunk circumference data.
Yield data was used to evaluate the method's accuracy. To test whether clustering of tree trunk circumference and ECa values could predict clustering of yield a one-way ANOVA test was applied. The sampled trees were divided into groups based on the output management zones. The dependent variable was yield variation (represented by its clustering intensity) and the independent variables were the management zones as delineated by ECa and tree trunk circumference values. The objective was to evaluate whether the group means of the dependent variable (yield) differed significantly among the groups of management zones. Results demonstrated that while trunk circumference values were a valid parameter for predicting yield variations, ECa values were not a sufficient indicator for yield prediction and could not therefore serve as a unique parameter for defining management zones in the orchard.
It has been demonstrated that point-based spatial-clustering methods and, in particular, the Gi* statistic represent a valid method for delineating management zones. However, since different parameters result in different management zones, it is important to first recognize the parameters that most influence yield variability and to develop the zones accordingly. As a method based on inferential spatial statistics, probabilities are assigned to management decisions. This supports reliable, informed decisions to advance sustainable and optimal management of orchards.

The procedure described above and applied on field trial 1 was repeated for data from field trial 2. Data were analyzed to recognize spatial variability, delineate management zones and quantify relations between parameters. The novel methodology was feasible for robust decision making promoting precision management of orchards. The automation of the method to create a decision support system that will generate management zones based on future scenarios would have a high potential for practical applications in variable climate conditions, but was only approached within the two-years project.
Irrigation maps were not found to be relevant or practical in either of the field cases. Instead of “irrigation” maps, we have developed “management” maps to aid growers in pruning, thinning, and harvesting their trees in order to maximize returns by optimizing fruit yield and quality in orchards. With the protocols developed growers can chose end characteristics that are most important and recognize spatial patterns of variables influencing them. Spatially significant patterns of the yield or quality influencing variables will enable precision management of trees to promote orchard performance and profit.

General description of the cooperation over the duration of the project

Overview
All partners met during kick-off, midterm, and strategic meetings. During field trials 1 and 2 only those partners with other work load were not participating, while 9 partners with various number of researchers were contributing to the measurements. Within each WP, meetings were held for technical exchange and cooperative measurements. Joined publications were approached and the publication work will be continued with partly already scheduled additional visits.

<u>Factual description of networking actions</u>

A. Networking inside the 3D-MOSAIC project

A.1 Meetings of all partners

A.1.1 Kick-off with all partners (14.-15. June 2011, Potsdam/Berlin, Germany)

A.1.2 Field trial 1 (7.-14. November 2011, Adana, Turkey)

A.1.3 Midterm Meeting with all partners and external project advisor Professor Dr. David Midmore (06.-07. June 2012, Milan, Italy)

A.1.4 Meeting of conference participants (11. July 2012, CIGR AgEng 2012, Valencia, Spain)

A.1.5 Field trial 2 (27.-31. August 2012, Potsdam, Germany)

A.1.6 Final strategic meeting with all partners, Versas through video conferencing, CU absent due to ended budget (23.-27. June 2013, EFITA conference, Turino, Italy)

A.2 WP Meetings

A.2.1 *WP3*: Alessandro Torricelli, Lorenzo Spinelli (PoliMi) by ATB (19.10.2011, Berlin, Germany)

A.2.2 *WP4*: Manuela Zude, Jana Käthner (ATB) work visit by CU for preparation of field trial 1 (22.-25. August 2011, Adana, Turkey

A.2.3 *WP1/2*: Vision group meeting by University Hohenheim (14.-15. September 2011, Hohenheim, Germany)

A.2.4 *WP6*: Manuela Zude (ATB) have been by ARO for field trial preparation and preliminary management maps data analyses and discussion; publication discussion for conference held in Leipzig 2012; potential of student exchange was pointed out (11.-19. February 2012, Tel Aviv, Gilat, Israel)

A.2.5 *WP5/6*: Pedro Arques, José Espinosa, NN (Versas), Amots Hetzroni, Alon Bengal (ARO) visited ATB for SRS and SAS discussion (13.-15. March 2012, Potsdam/Berlin, Germany)

A.2.6 *WP5*: Versas and ARO (several occasions, spring 2012, video conferencing)

A.2.7 *WP2*: Florian Pforte (University Kassel) traveled to Swiss partners (ART, ZHAW) for handing over 2D algorithms for canopy (and fruit) estimation (spring 2012, Switzerland)

A.2.8 *WP1/2*: Thomas Anken (ART), Vincent Meiser, Dejan Seatovics (ZHAW), Jörn Selbeck, Rolf Adamek (ATB), Hans-Werner Griepentrog, Claes Jäger-Hansen (University Hohenheim) on the development of protocols and platform set-up (23.-25.July 2013, Hohenheim, Germany)

A.2.9 *WP1/2*: Claes Jäger-Hansen, Vincent Meiser, Jörn Selbeck during field trial 2 (30. August 2012, Potsdam, Germany)

A.2.10 *WP1/3*: Theodore Fronimos (AUTH), Paolo Rossi (Sintéleia), Manuela Zude (ATB) during field trial 2 (30. August 2012, Potsdam, Germany)

A.2.11 *WP5/6*: Aviva Peeters, Alon Bengal, Amots Hetzroni (ARO), José Espinosa, Pedro Arques (Versas), Manuela Zude, Jana Käthner (ATB) during and subsequently to field trial 2 for data transmission to GIS (30. August and 5. September 2012, Potsdam, Germany)

A.2.12 *WP3*: Manuela Zude (ATB) for carrying out measurements on phantoms and discussion on publication by PoliMi. Manuela Zude meeting with Sintéleia on reporting and experiment scheduling (16.–28.10.2012, Mlan/Bologna, Italy)

A.2.13 *WP4*: Mustafa Unlu, Riza Kanber (CU) and Manuela Zude on continuous measurements in the experimental orchards and soil analyses for both sites (throughout the years 2012/2013, email conversation)

A.3 Bilateral exchanges

A.3.1 *WP4*: Robin Gebbers, Jörn Selbeck (ATB) carried out soil readings by CU in the experimental citrus orchard used for field trial 1 (24.-27. May 2011, Adana, Turkey)
A.3.2 *WP3*: Jana Käthner, Jörn Selbeck, Birgit Seifert (ATB) measured apples, citrus, and plum by PoliMi (four measuring dates in 2011, Milan, Italy)
A.3.3 *WP2*: Florian Pforte (University Kassel) performed photogrammetric readings in the plum orchard also used in field trial 2 at ATB (three measuring dates in 2011, Potsdam, Germany)
A.3.4 *WP2*: Florian Pforte visited ATB for finalizing a publication on former measurements (spring 2012, Potsdam, Germany)
A.3.5 *WP1/3*: Budget and conceptual discussion of AUTH and ATB (several occasions in winter 2011 and spring 2012, video conferencing)
A.3.6 *WP1/3*: Theodore Fronimos (AUTH) carried out measurements on trees without leaves by ATB (November 2012, Potsdam, Germany)
A.3.7 *WP6*: Jana Käthner (ATB) work visit by ARO for meta data and discussion on spatial data analysis (12.-16. April 2013, Tel Aviv, Gilat, Israel)
A.3.8 *WP3*: Two horticulture students (Jakob Kunzelmann, Vinh Lai) of ATB performed their curricula-relevant internship hosted by ARO targeting the application of 3D-MOSAIC fruit sensors (spring/summer 2013, Gilat, Israel)

The meetings and video conferences were accompanied by numerous email and video conversations.

B. Networking outside the present project

- B.1 Meeting of University Hohenheim group with external partners at DTU (Technical University of Denmark) about platform navigation and laser scan handling (e.g. for tree mapping)
- B.2 Contact to automation and robotics group at the Washington State University (Professor Qin Zhang), preparation of cooperation contract
- B.3 Information exchange with CIGR section chairs. As an outcome a separated section for presenting first results of 3D-MOSAIC was organized at the world congress CIGR/AgEng2012 held in Valencia (Spain) in July 2012
- B.4 Workshop on commercial GIS solutions held during field trial 2 (29. August 2012, Potsdam, Germany)
- B.5 New project proposals were developed within the group and with new partners such as: 1. Project “USER-PA” with founding starting in March 2013 by the ICT-AGRI founders group. 2. Bilateral project proposal between Greece and Germany was submitted. 3. ICT-AGRI project proposal on photogrammetry applications was developed by Swiss groups and University Hohenheim.
- B.6 Young scientists staying at ATB for work visits were integrated in running measurements within WP3 on emerging technologies for fruit sensing (Delia Lorente, Valencian Institute for Agricultural Research, IVIA, Spain and Kaveh Mollazade, Tehran University)
- B.7 Student internships have been planned in cooperation of ATB and responsible partner at AUTH, who is presently employed at the University of Davies, US.

Impact statement

3D-MOSAIC partners of different focus considering the stakeholders (companies, university and non-university research institutions) and technical background (ICT development specialists partners meet agricultural engineering partners) shared their knowledge, experience, and infra-structure (laboratories, computer resources, prototypes, software, novel sensors, experimentation fields, models) with unique profiles in order to open opportunities for synergies which resulted in a comprehensive look on the question. The transnational interdisciplinary consortium brought together partners with expertise in a diversity of technology oriented scientific disciplines: robotics and automation engineering, vision systems, plant physiology, plant sensors, GIS, and irrigation.

Partners from southern and northern regions of EU collaborated within 3D-MOSAIC and imply relevance of the tackled issue. For example does citrus production play a crucial role – economically and ecologically - in Spain, Greece, and Turkey while Italy, Switzerland and Germany are important plum producing countries. However, the topic of the joint research is highly relevant throughout Europe due to its wide applicability in tree crop production systems with water management requirements (crops of the temperate and Mediterranean zone, subtropical like citrus, stone fruit, pip fruit as well as in viticulture).

Within 3D-MOSAIC interactance was visible in the thematic groups of (i) the robotic and sensor groups, and (ii) the plant physiologists and application groups as well as within the 6 work packages, the project partners built new cooperations due to synergistic work field, experiences of measuring on the same target, and intensive communications and exchanges. The interdisciplinary cooperation definitely increased the knowledge of all partners, and opened minds for precision horticulture. The enthusiastic and critical discussions with the often synergistic technical and social background certainly had a high impact on future projects. The effects may last, since mainly senior scientists as multiplicators were heading the projects. Project partners involved few postdocs, but several young researchers in different stages of their career.

Young scientists were easy to attract for this transnational project, while the community often complains about the missing applicants in the field of agricultural engineering. Exemplarily for young researchers involved: Jana Käthner born Beerbaum (f, PhD candidate; ATB); F.H. Brand (m, Dipl.-Ing., Junior Assistant, Mechatronics, ZHAW); Claes Jaeger-Hansen (m, MSc. E. Electrical Engineering – Robotics and Automation, UniHoh); Levet Koç (m, PhD student, CU); Ugur Kekeç (m, PhD student, CU); Vincent Meiser (m, Dipl.-Ing., Geodesy, ZHAW); Servet Tekin (m, PhD student, CU); Filiz Ünlü (f, PhD Student, CU); graduate student (m, PoliMi); Eugen Klauke (m, undergraduate students, ATB); Sandra Heim (f, undergraduate student, ATB); Julia Weidner (f, undergraduate student, ATB); Jakob Kunzelmann (m, undergraduate student, ATB); Vinh Lai (m, undergraduate student, ATB).

Also, as another example for the involvement of young researchers, the work on emerging technologies was supported by the fortunate coincidence of having PhD candidates from Spain and Iran in the ATB laboratory. Ms Delia Lorente (IVIA) focused during her three months internship on the particular topic of citrus decay detection by means of backscattering imaging (WP3.2), while Kaveh Mollazade (University Tehran) worked on advanced data processing of spatial spectroscopy (WP3.2).

Finally a comment from the external project advisor: “The level of enthusiasm, of cross-disciplinary conversations and comprehension between the participants was infectious.”

Exploitation and dissemination measures

Project website

www.atb-potsdam.de/3D-MOSAIC/ presenting three 3D-MOSAIC Newsletters The 3D-MOSAIC webpage will be maintained until 2015.

Data access: The operational GIS data management platform can be accessed. by http://www.versas.es:8080/GIS3DMosaic/ and GIS sDSS platform by http://www.versas.es:8080/BANET/ after accounting measures by Versas.

Journal articles

a) Pforte F; Selbeck J; Hensel O. (2012). Comparison of image analysis and laser scanner technique for automated estimation of the leaf area on tree level. Biosystems Engineering Volume 113: 325-333

b) Vougioukas S; Anastassiu HT; Regen C; Zude M (2012). Influence of foliage on radio path losses (PLs) for wireless sensor network (WSN) planning in orchards. Biosystems Engineering 114: 454-465

c) Zude M; Peeters A; Selbeck J; Käthner J; Gebbers R; Ben-Gal A; Hetzroni A; Jaeger-Hansen C; Griepentrog HW; Pforte F; Rozzi P; Torricelli A; Spinelli L; Ünlü M; Kanber R (2012). Advances in precise fruit production. Agricultural Engineering 67: 338–341

d) Lorente D; Zude M; Regen C; Palou L; Gómez-Sanchis J; Blasco J (2013). Early decay detection in citrus fruit using laser-light backscattering imaging. Postharvest Biology and Technology, Volume 86, 424-430

e) Mollazade K; Omid M.; Akhlaghian Tab F; Rezaei Kalaj Y; Saeid Mohtasebi S; Zude M (2013) Analysis of texture-based features for predicting mechanical properties of horticultural products by laser light backscattering imaging. Computers and Electronics in Agriculture, Volume 98, 34-45

Conference proceedings

1. Käthner J; Rozzi P; Zude M (2012). Correlation analyses of high resolution 3D soil electrical conductivity and thedevelopment of fruit trees. CIGR-AgEng International Conference of Agricultural Engineering, Proceedings 69-72. ISBN-10: 84-615-9928-4

2. Torricelli A; Spinelli L; Käthner J; Selbeck J; Franceschini A; Rozzi P; Zude M (2012). Non-destructive optical assessment of photon path lengths in fruit during ripening: implications on design of continuous-wave sensors. CIGR-AgEng International Conference of Agricultural Engineering, Proceedings 84-88. ISBN-10: 84-615-9928-4

3. Vougioukas SG; Anastasiu HT; Regen Ch; Zude M (2012). Comparison of radio path loss models for wireless sensor networks in orchard environments. CIGR-AgEng International Conference of Agricultural Engineering, Proceedings 79-83. ISBN-10: 84-615-9928-4

4. Jaeger-Hansen CL, HW Griepentrog, JC Andersen (2012). Navigation and tree mapping in orchards, International Conference of Agricultural Engineering, Proceedings 89-94. ISBN-10: 84-615-9928-4

5. Hetzroni, A., Peeters, A., Ben-Gal, A. (2012). Towards precision management of orchards: using automated monitoring to build a GIS-based spatial decision support system. International Conference of Agricultural Engineering, Proceedings 73-78. ISBN-10: 84-615-9928-4

6. Seifert B; Pflanz M; Schlüter O; Zude M (2012). Spectral Properties of Chlorophyll and Chlorophyll Catabolites: A Fine-scaled and Non-destructive Characterisation of Ripeness-related Chlorophyll Contents in Climacteric Fruits? Proceedings-CD of CIGR Technical Postharvest Symposium, Stellenbosch

7. Käthner J., Selbeck J., Herppich W. B., Adamek R., Zude M. (2013). Zusammenhang von Thermografie-Bildern der Kronenoberfläche mit Ertragsparametern in einer *Prunus domestica* Produktionsanlage, CBA-UAS-Workshop, Proceedings
8. Anastassiu H.T., Fronimos T., Regen C., Vougioukas S.G., Petrou L., Zude M. (2013). "A Computational Model for Radio Wave Propagation within Wireless Sensor Networks in Orchard Environment" EFITA-WCCA-CIGR Conference "Sustainable Agriculture through ICT Innovation", Turin, Italy, 24-27 June 2013, p 861-868
9. Anken T., Battiato A., Seatovic D., Meiser V., Selbeck J., Pforte F. (2013). "Canopy-Area Measurement of Plum Trees using Laser and Near-Infrared Imaging" EFITA-WCCA-CIGR Conference "Sustainable Agriculture through ICT Innovation", Turin, Italy, 24-27 June 2013, p 861-868
10. Spinelli L., Franceschini A., Rozzi P., Torricelli A. (2013). "Advanced Optical Sensors for Non-Destructive Monitoring of Fruit quality Parameters during Growth" EFITA-WCCA-CIGR Conference "Sustainable Agriculture through ICT Innovation", Turin, Italy, 24-27 June 2013, p 320-324
11. Peeters A., A. Ben-Gal A. ,Hetzroni A. (2013). "A GIS Spatial Model for Defining Management Zones in Orchards Based on Spatial Clustering" EFITA-WCCA-CIGR Conference "Sustainable Agriculture through ICT Innovation", Turin, Italy, 24-27 June 2013, p 1185-1192

Conference presentations

1. Beerbaum J., Selbeck J., Robin R., Rezaei Y., Zude M. (2012). A sensor based approach to understand spatial variability in orchards, GIL- Conference, Germany Jan. 2012 (poster)
2. Peeters A., Ben-Gal A., Hetzroni A., Zude M. (2012). Developing a GIS-based spatial decision support system for automated tree crop management to optimize irrigation inputs. International Environmental Modelling and Software Society (iEMSs). 2012 International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany (oral)
3. Pforte F (2011). Presentation of the project in the course of the international alumni´s winter school 2011 of DAAD, held at the Department of Agricultural Engineering of the University of Kassel (oral)
4. Jaeger-Hansen C., Griepentrog H. W., Andersen J. C. (2012). Navigation and tree mapping in orchards, International Conference of Agricultural Engineering. Valencia, Spain, July 8-12, 2012. (oral)
5. Hetzroni, A., Peeters, A., Ben-Gal, A. (2012). Towards precision management of orchards: using automated monitoring to build a GIS-based spatial decision support system. International Conference of Agricultural Engineering. Valencia, Spain, July 8-12, 2012. (oral)
6. Käthner J., Rozzi P., Zude M. (2012). Correlation analyses of high resolution 3D soil electrical conductivity and time series of fruit quality features, International Conference of Agricultural Engineering. Valencia, Spain, July 8-12, 2012. (oral)
7. Richter U., Pforte F., Selbeck J. (2012). Comparisons of Leave area estimations via laser –scanner readings and image analysis, International Conference of Agricultural Engineering. Valencia, Spain, July 8-12, 2012. (poster)
8. Torricelli A, Spinelli L., Käthner J., Selbeck J., Franceschini A., Rozzi P., Zude M. (2012). Non-Destructive optical assessment of photon path lengths in fruit during ripening implications on design of continuous-wave sensors International Conference of Agricultural Engineering. Valencia, Spain, July 8-12, 2012. (oral)
9. Vougioukas S, Anastassiu H., Regen C., Zude M. (2012). Comparison of radio path loss models for wireless sensor networks in orchard environments. Paper C-1078. International Conference of Agricultural Engineering (CIGR-Ageng conference 2012). (oral)

10. Griepentrog H. W., Jaeger- Hansen C., Dühring K.(2012) electric agricultural robot with multi-layercontrol. C-1449. International Conference of Agricultural Engineering (CIGR-Ageng conference 2012). (oral)
11. Käthner J., Gebbers R., Herppich W., Rezaei Y., Zude M. (2012) A sensor based approach to understand spatial variability of plant parameters in orchards, 2nd international conference on Hydropedology, 22-27 July 2012, Leipzig, Germany
12. Seifert B., Schlüter O., Zude M. (2012). Spectral properties of chlorophyll and chlorophyll catabolites: a fine-scaled and non-destructive characterisation of ripeness stages in climacteric fruits? CIGR International Technical Symposium on “Innovating the Food Value Chain, Postharvest Technology and Agri-Food Processing” held in Stellenbosch, South Africa, 25-28 November, 2012 (oral)
13. Zude M. (2012). Advances in non-destructive quality measurements of food & agro products. CIGR Technical Postharvest Symposium Stellenbosch, Südafrika (keynote speech)
14. Zude M.(2013): Final 3D-MOSAIC Presentation, EFITA-WCCA-CIGR conference, 23-27 June, 2013 Turin, Italy (oral)
15. Käthner J., Herppich W., Adamek R., Zude M.: Influence of soil variability and topography on plant growth and yield parameters in Prunus domestica orchard, EFITA-WCCA-CIGR conference, 23-27 June, 2013 Turin, Italy (oral)
16. Anastassiu H. T., Fronimos T., Regen C., Vougioukas S.G., Petrou L., Zude M. “A Computational Model for Radio Wave Propagation within Wireless Sensor Networks in Orchard Environment” EFITA-WCCA-CIGR Conference “Sustainable Agriculture through ICT Innovation”, Turin, Italy, 24-27 June 2013 (oral)
17. Anken T., Battiato A., Seatovic D., Meiser V., Selbeck J., Pforte F. “Canopy-Area Measurement of Plum Trees using Laser and Near-Infrared Imaging” EFITA-WCCA-CIGR Conference “Sustainable Agriculture through ICT Innovation”, Turin, Italy, 24-27 June 2013 (oral)
18. Spinelli L., Franceschini A., Rozzi P., Torricelli A.. “Advanced Optical Sensors for Non-Destructive Monitoring of Fruit quality Parameters during Growth” EFITA-WCCA-CIGR Conference “Sustainable Agriculture through ICT Innovation”, Turin, Italy, 24-27 June 2013 (oral)
19. Käthner J., Gebbers R., Zude M. (2013). Aufnahme von Boden- und Pflanzendaten für ein ortsspezifisches Management in Obstanlagen. DGG 27 February - 1 March, 2013, Bonn, Germany (oral)

<u>Stall by International Fair trade</u>

1. Griepentrog HW, Jaeger-Hansen C (2011). Autonomous platform at fair trade Agritechnica, Hannover
2. Zude M, Foltan H (2011). 3D-MOSAIC-Information/Newsletter. Fair trade Agritechnica, Hannover.
3. Käthner J (2013). Fruit sensors for in-situ analysis. IPM Essen, Januar, Messegelände Essen

<u>Press - examples</u>

1. Infoagro/Spain (2011/03), "Proyecto europeo para el desarrollo de unsistema de monitorización de los procesos grícolas"
2. ATB press release (2011/06), "Transnational ERA-Net project 3D-MOSAIC targeting efficient irrigation in fruit crops started in Potsdam"
3. BLE press release (2011/06, in German), "Transnationales EUForschungsprojekt: Obstkulturen effizienter bewässern"
4. LE Newsletter (2011/06), "Successful start for ICT-AGRI Project ―3DMosaic in Potsdam", Page 8
5. Beuth Presse (2011/10), Automatisierte Bewässerung, Page 31

6. IDW News: (2011/06), "Transnational ERA-Net project 3D-MOSAIC targeting efficient irrigation in fruit crops started"