AUTOMATED LOCATION OF TREE POSITION FOR ESTIMATING APPLE YIELD BY USING AN ANDROID MOBILE PHONE

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Abstract: *The accuracy of forecasts depends on the method used and the number of data samples taken in the orchard. An automated system for simple and fast data acquisition consists of an application on a personal computer (PC) for user to create a daily journey through the plantations and export the data to a navigation device. The second part represents an android mobile phone (AMP), which serves for capturing various data, such as positions and images when inspecting the plantations and data. Processing of all collected data runs on a PC, which requires a synchronization of all new, changed or updated data stored in the AMP's database with the database on the PC. After testing the procedure in two successive growing seasons in 245 intensive apple orchards, orchard register inaccuracy and GPS errors were detected as most frequently in the first year. After introducing the automatic discovery of orchards into the procedure, the accuracy of detected position rose from 91.98 % in the first year to 99.99 % in the second.*

Key words: *AMP, positioning, orchard, sampling*

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1. Introduction

Production forecasting is an important factor in precision management of orchard (Gong et al., 2013). It provides the guidance to farmers on product price and effectively managing the market variables.

Yield estimation of fruit would provide valuable information for generating prescription maps for precision management (Bargoti & Underwood, 2017). During the past few decades, there had been several studies on fruit yield estimation. During the past few decades, there had been several studies on fruit yield estimation. Wang et al. (2013) used an autonomous orchard vehicle with two-camera rig to take pictures and estimate apple orchard yield by developing new apple detection algorithms on computer. Dorj et al. (2013) applied digital camera to capture images, remove noises divide images into sub-images and detect the white pixels to estimate the yield of Tangerine flower. The research on the fruit yield estimation is not only important for individual farmers (Moonrinta et al., 2011), but also has a profound impact on the development of agricultural management policies at regional and national levels.

In the European Union (EU-28), about 10 million tons of apples are harvested every year (WAPA, 2019), which makes it the second most important fruits after the olives. In Slovenia the cultivated area of apple fruits was 2700 ha and the total production was 80.000 tons in 2018, both ranking it first among all fruit crops produced (Ministry of Agriculture, Forestry and Fisheries of Slovenia, 2019).

However, apple production suffers from alternate bearing, which leads to temporal variation in fruit yields as well as fruit quality also on individual trees thus effecting the accuracy of the forecast. Despite applying of fruit thinning (removing young fruits in the early season) and plant growth regulators, which manage the alternate bearing and improve fruit quality (Iwanami, 2018), the yield information of individual trees is a prerequisite for the successful application of forecasting models (Stajnko et al., 2013). With the decrease in cost of hardware devices and the rapid progress in the field of artificial intelligence (Panzieri et al. (2007), fruit yield estimation devices are becoming smaller and simpler to use. To achieve the 95 % accurate forecast as required by producers, it is desirable that each year the same trees be located and captured by digital camera, because the potential yield of each individual tree depends on its possible alternative bearing and site-specific conditions (Noguchi et al., 2003).

For this reason, the accurate positioning system running in orchards is a perfect task for autonomous yield mapping, because the same trees have to be captured by a digital camera year after year (Stajnko et al., 2011).

Therefore, it is important to obtain and map the potential yield information of individual trees for tree-specific implementation of alternate bearing control measures and other management practices (Berk et al. 2016). The RFID and barcode registration insures the highest possible accuracy (Lorincz & Welsh (2007), but require manual work to adjust the labels systems ensure on particular trees (Triolo et al., 2007), thus, the GPS technologies seem simpler and more convenient (Madria et al. 2002).

Since our method for predicting yield based on previous forecasts and comparison with actual production (Stajnko et al., 2004), it is desirable that each year the same trees are being located and captured by AMP or tablet.

Such data acquisition enables capturing of many samples of different apple and pear varieties at various farmers in a short time in order to improve the accuracy of the forecasting on local level.

With the decrease in cost of hardware devices and the rapid progress in the field of artificial intelligence, fruit yield estimation devices are becoming smaller and simpler to use (Cubero et al., 2018). Since modern android mobile phones (AMPs) are now integral to data recording and data management in the field, an electronic field data capture has proved to be an effective alternative to paper-based modes of data recording, because it is more efficient and less open to transposition error. The greater rate of data capture can provide opportunity for increased sampling intensity or free up time for error checking and data analysis (Gazcón, et al., 2018).

On the other hand, integrated to AMPs GPS has also become more reliable and accurate over recent years, with some handheld differential GPS devices now capable of producing sub-metre accuracy in real time (Wagtendonk & De Jeu, 2007).

The chapter describes an AMP based system that enables a satellite control guiding to the selected orchard for locating and capturing the tree image as quickly as possible, especially if we want to compare the tree's specific data with the previous calendar year. It provides the data acquisition with minimal equipment and efficient access to the information contained on the ground for further processing. Besides, simultaneous converting of a GPS coordinate system into the horizontal state coordinate system Gauss Kruger D48, implemented in the procedure is described. The effectiveness of the novel system for tree positioning and apple yield forecasting of the Slovenian apple producers is discussed in the following subchapters.

2. FK mobile software

2.1 Register of orchard

In 2005 Slovenian Ministry of Agricultural formed a graphical database of agricultural land use called GERK (2017) for all farmers. GERK is a completed unit of agricultural land, and usually consist of more orchards with several different apple varieties. Data on the geographical position are held by the Ministry and was also a source for our application. The complete base of GERKs borders contains over 900 MB, however for our use in orchards only 1.8 MB had to be stored and processed in a mobile device. There are several different formats used for the GERK encoding, which we are describing in the following paragraphs.

An ESRI Shapefile format is intended to store the data in the Slovenian GIS for agricultural land, which is defined by three special files, SHP, SHX and DBF. The contents of these files are binary. For the encoding a format "least significant byte first (Little-Endian)" or "most important reason first (Big-Endian)" can be used. An SHP file contains all the geometric data GERKs, whereby the border of an individual GERK is presented as a set of points or a polygon in the coordinate system. All coordinates in these files are recorded in the Gauss Kruger D48 coordinate system.

In parallel with data for the whole polygon, which contain the borders of a GERK written as an SHX index file, a minimal rectangle that contains the minimum polygon information is also recorded in the file 'Containment rectangle'. Next to each identifier, GERK enters a deviation in the SHP file where one can find geometric information for a particular GERK. The area and use information for an individual GERK is recorded in the DBF file.

The algorithms have been implemented for AMP using the open- source BSD-license as well as OpenCV library (https://opencv.org/), the open software development kit (SDK) for Android (https://developer.android.com/studio) and the programming environment Eclipse (http://www.eclipse.org/org/documents/epl-v10.php) using Java language to complete the algorithms and man-machine interface.

2.2. Data acquisition system

After examining the project requirements, we decided to prepare the algorithm which enabled an operator to organize for departure in the orchard already in the office at a personal computer (PC).

For this reason the system consists of the following three subsets:

a) Application to capture data on the ground, running on an AMP Huawei Honor 6 Plus
b) Database for central storage of collected field data on a PC
c) Applications for reviewing of collected data.

The latter two are installed and run on a PC containing also a central storage of data for subsequent processing of collected data (images), required for annual crop forecast of selected fruit culture. Before travelling in the terrain, the user makes a daily plan by selecting GERKs or indirectly orchards, from which he will collect data for forecast. Then positions of GERKs are exported to the android mobile phone in GPX file, which is loaded on Google Maps application (https://www.google.com/maps, 2019), originally intended to road navigation. Additionally, our application also provides an overview of all producers of agricultural land, GERKs, orchards and varieties.

The central part of the system represents the AMP, which leads the user to selected GERK or orchard. Integrated GPS receiver and camera enable the user to locate easily the tree position; capture and store the image in the AMP memory card; from where the forecast app can be proceed.

As seen in Figure 1, a full system uses two instances of the database. The first is stored on a PC and the other on the AMP. Since the data recorded on the ground are located to the mobile base, two bases no longer have the same content. Therefore, the application has to be synchronized after each recording in the orchard.

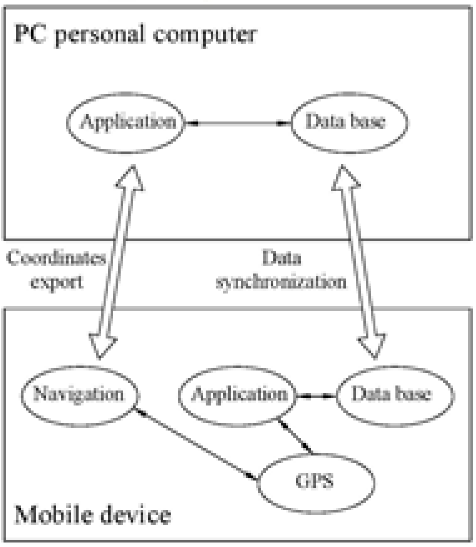

Fig. 1. System architecture.

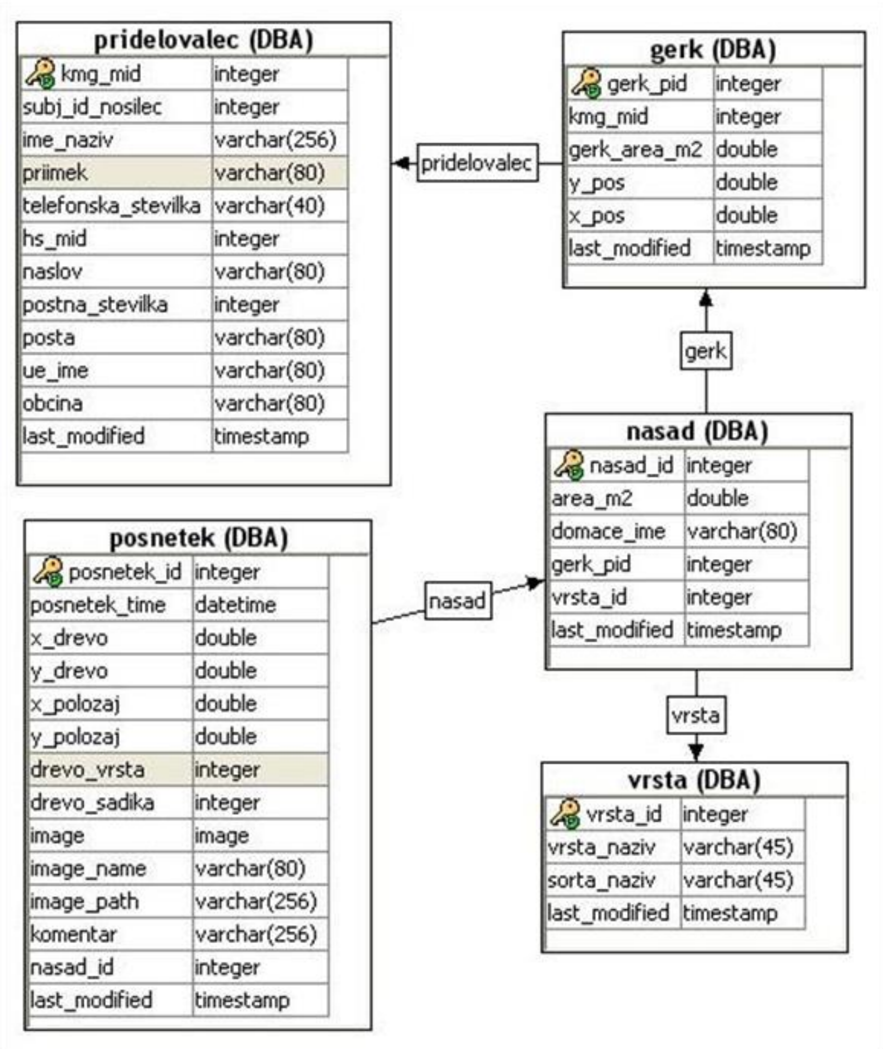

Fig. 2. Diagram of the database.

2.3. The structure of the database

Figure 2 shows shows all database tables applied in our application. It consists of five tables: producer (‘pridelovalec’), image (‘posnetek’), GERK, orchard (‘nasad’) and row (‘vrsta’). The table ‘pridelovalec’, producer, contains information such as name, company name, address and postal code for all orchards owners. GERK contains x and y-coordinates as Gauss Kruger D48 (http://prostor.gov.si, 2009) and the area. Each GERK usually consists of one or more orchards; thus the table ‘gerk’ contains information about the area of the orchard and the variety of trees. The table ‘posnetek' contains information about the position of trees, date and time of image capture, commentary and the identifier of the orchard in which the recording was made. The file row also contains data about the row from which the image was captured.

Coordinate systems

Because the Slovenian public administration is still using the Gauss-Kruger D48 coordinate system, the application should first perform a conversion of coordinates between a WGS84, used by GPS satellite navigation, and D48. Basically, WGS84-coordinates are the geographical coordinates, while the D48 are planar (map) coordinates.

Figure 3 shows the procedure for conversion between coordinate systems. As can be seen, a WGS84 geographical coordinates are first converted into geocentric coordinates on a WGS 1984 ellipsoid. Then WGS 1984 are transformed into the geocentric coordinates on a Bessel ellipsoid by a Helmert 7-parameter transformation. The Bessel geocentric coordinates are further transformed into the geographic coordinates and finally projected into D48 coordinates. Further conversion equations can be found in (ESRI, 2016) and parameters for Slovenian D48 conversion in Application of Geodetic Datums (Zgonc, 2006).

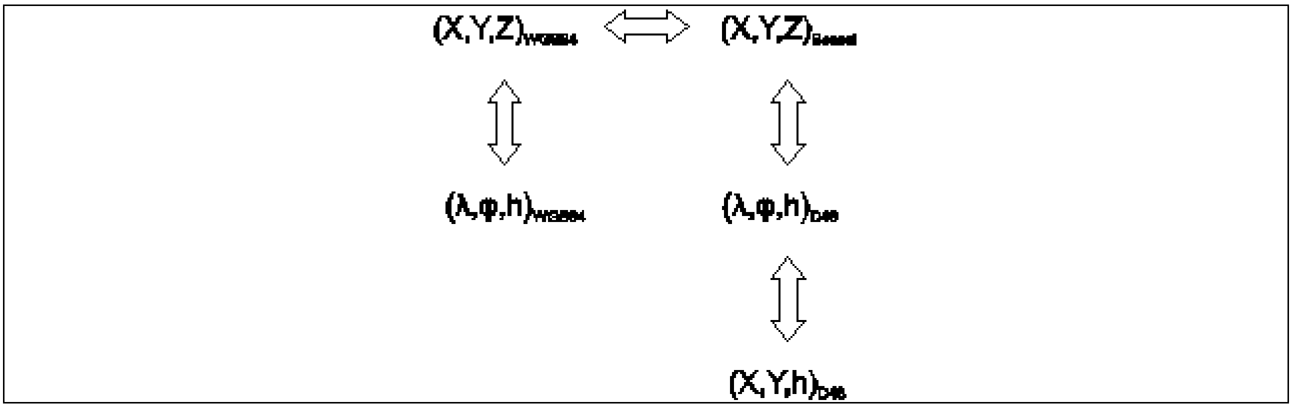

Fig. 3. Conversion of WGS84 coordinate system and Gauss-Kruger D48.

2.4. Field data capture

The user captures data in the field by applying a mobile application. Before the system begins to guide the user on the roads, he must check out the quality of the GPS signal in the form of PDOP, HDOP, VDOP values on the ‘Status’ graphic interface (‘Status’ image in Figure 4); it should be lower than 2.0.

If the signal quality is good enough i.e. – below a given threshold –a more accurate position is computed as an average position of n measurements. The n represents an input argument, usually set to 5. Since the GPS module returns a GPS position once per second, waiting computation time is also around 5 seconds.

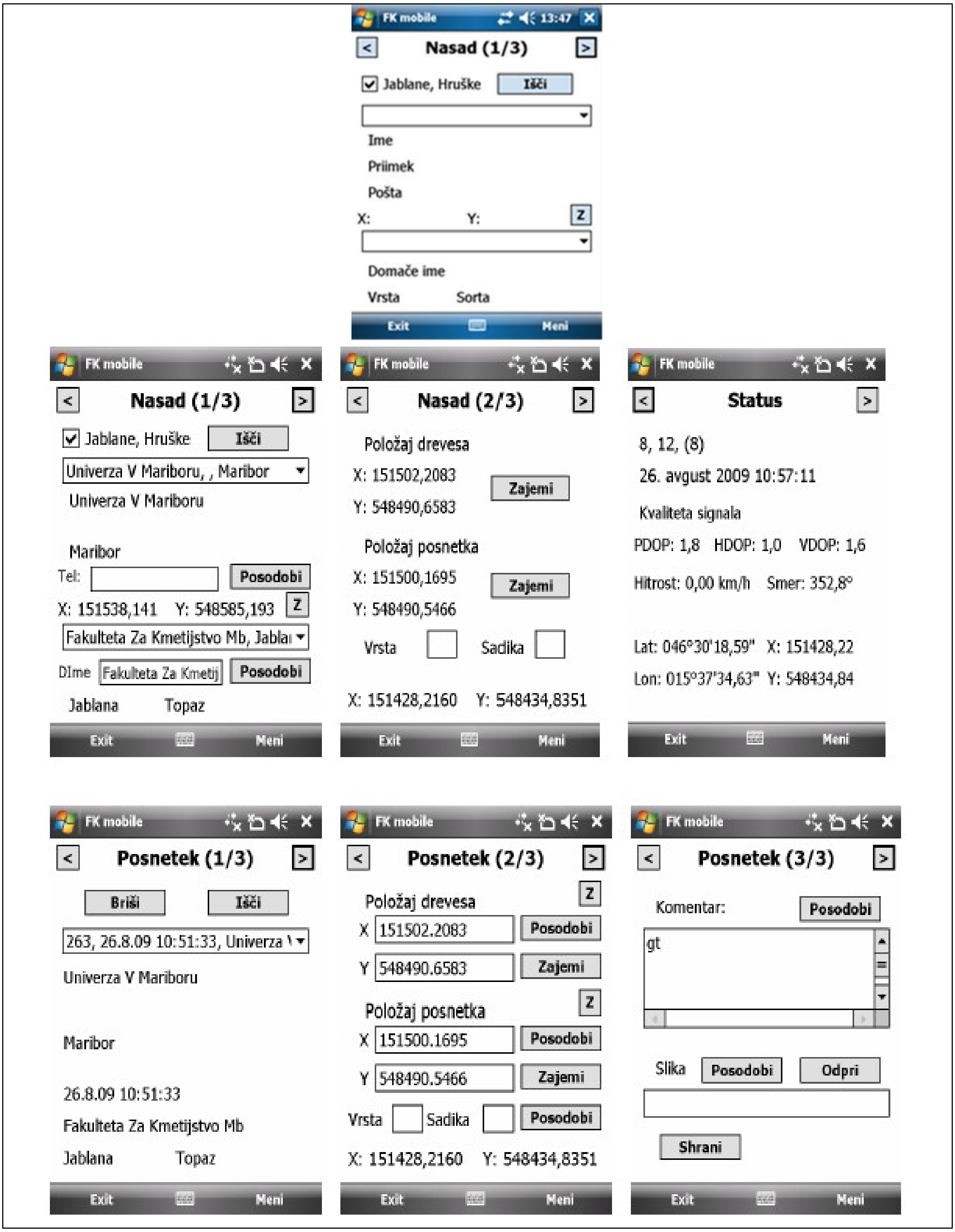

Fig. 4. The graphical interface for capturing data on site (left).

Once the user steps into the orchard, the mobile application shows the graphic interface 'Nasad 1/3' (Figure 4), with data for the GERK on which he is standing, according to the position conveyed by the GPS device. The user must now confirm the GERK and orchard in which he is currently located. Additionally, the user can check the apple variety in each plantation, since there is a label with information on species and variety. Finally ('Posnetek 3/3 in Figure 4), the following data can be additionally stored in the database:

- contact details of the owner of the selected GERK,
- local name of the plantation, which is defined by the owner of the orchard,
- the position of trees, which will be photographed,
- the position of trees to be photographed,
- the position from which an image is recorded,
- a photo of the tree.

2.5. Data synchronization

Since there are two partial databases (one on the PC and another on AMP) the user has to connect the AMP to the server system on PC and perform data synchronization after completion of the fieldwork user. Any changes from the central database are transferred into the database of AMP and vice versa. Architecture data model allows the simultaneous collection of data to multiple users on the ground.

Graphical interface (Figure 5) gives an overview of all images captured in the last calendar year also on the PC, which allows additional statistical analysis and planning of future journeys on the plantations. Figure 6 represents the graphical interface and its components for exporting route to the mobile navigation application in GPX format.

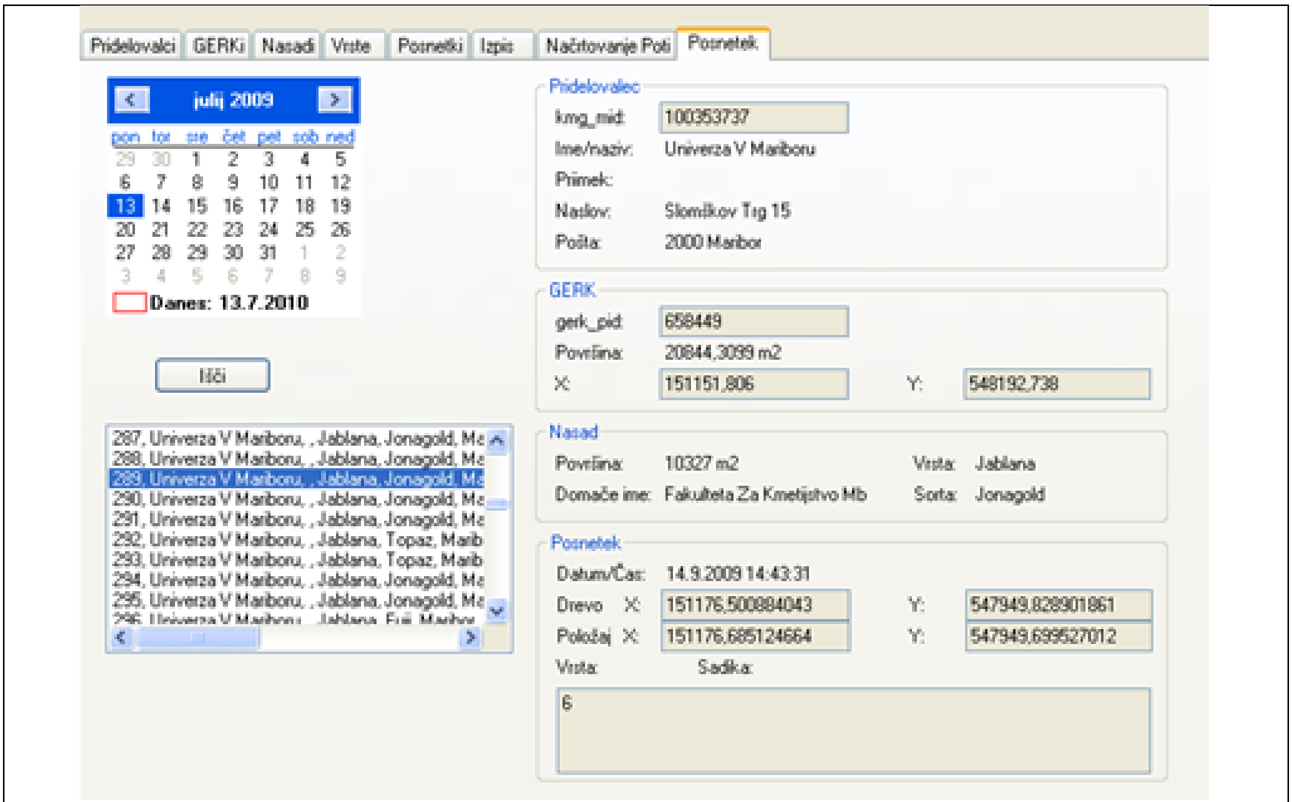

Fig. 5. Overview of all images captured in the last calendar year.

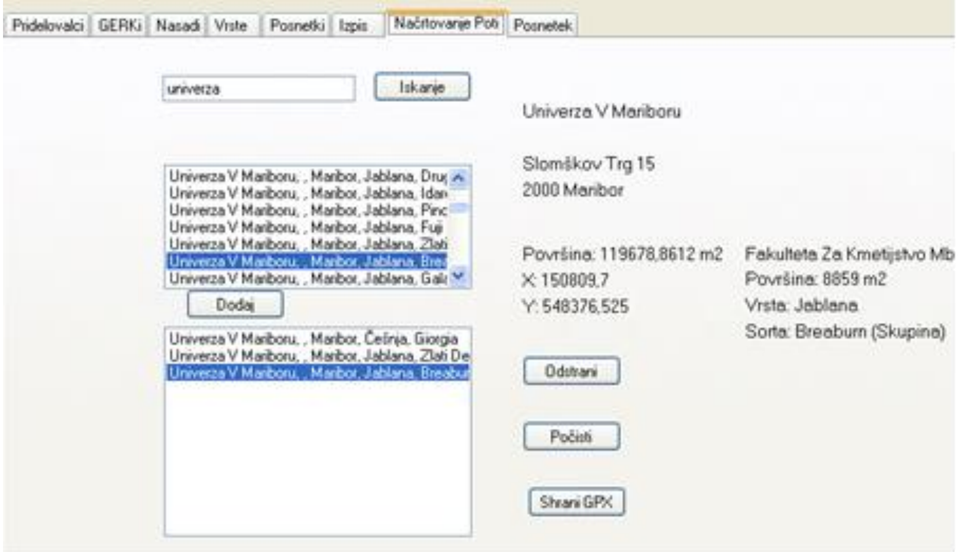

Fig. 6. Route planning in selected plantations and graphic components for export route.

2.6. Local navigation - containment test

Each GERK is described as a polygon in D48 coordinates and is read from the structural files, as described in subsection 2.3. By using the GPS receiver on the ground, one can read a position on the Earth's surface. Since the receiver returns the coordinates in the WGS84 system, for our purposes they have to be converted back into coordinates of the Gauss-Krueger D48 as shown in the section 2.3.

On particular location in the field there is usually a situation where several plots containing their own polygon are being limited by their individual GERK. However, only after correct determination of our position with a containment test, can we be sure whether we are inside or outside a selected GERK. The special mathematical procedure is explained on the basis of Figure 7, which shows a polygon with vertices ABCDE and the point within the polygon O.

The procedure takes several steps, described by Berg et al., 2009. First, a sum of angles formed by the point O and of all adjacent vertices on the polygon is calculated. When the point O lies inside the polygon, the sum is 2π; if the point O lies outside the polygon, the sum is 0. This procedure also works for concave polygons, which is illustrated in Figure 7.

Since there are more than 5000 fruit orchards in Slovenia, testing whether we are located inside a polygon of all orchards is time consuming and leads to unnecessary battery consumption. Therefore, the improved algorithm is implemented according to which all orchards are sorted by the *x* coordinate in one list and by the *y* coordinate in the second list. By bisection in both lists a minimized set of potential orchards is found by using the following criterion:

$$O \in \min(S_{x_i}) < A_x < \max(S_{x_i}) \cap \min(S_{y_i}) < A_y < \max(S_{y_i}) \qquad (1)$$

where $\min(S_{x_i})$ is the minimal and $\max(S_{x_i})$ the maximal *x* coordinate of orchard S_i (resp. for coordinate *y*). A_x and A_y are *x* and *y* coordinates of the current position.

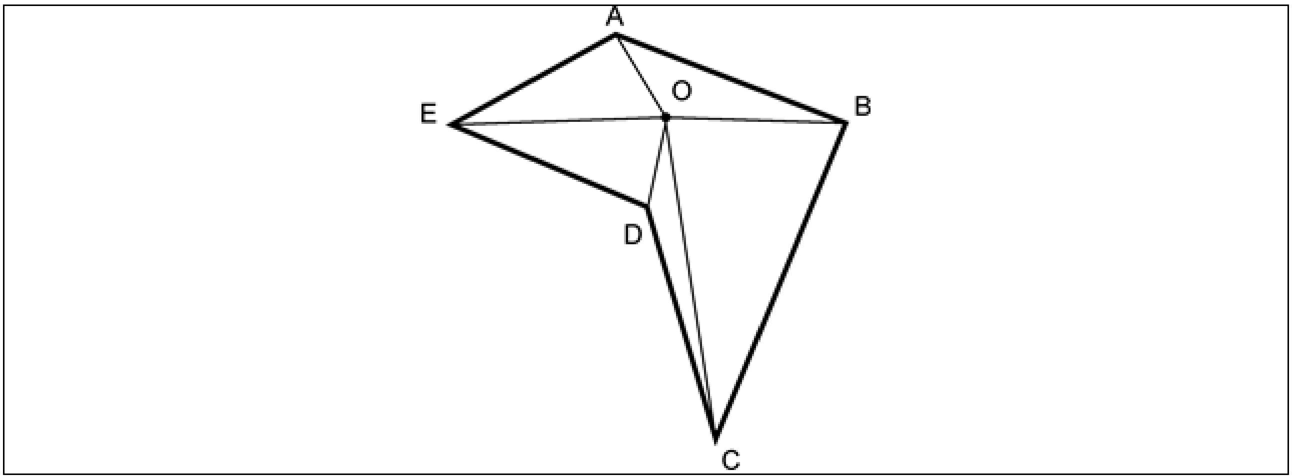

Fig. 7. Containment test.

2.7. Micro navigation - local governance

The application also allows viewing of data that were stored during previous recordings (‘Posnetek 1/3’). Moreover, one can also find all information about the current situation and all near-recorded positions in the recent past. Relevant information about the centre of each GERK, the name of the plantation, the position of the tree and the tree image (‘Posnetek 2/3’ in Figure 4), will be retrieved from the database of AMPs.

The mobile application is able to guide the user to local position by built-in compass (Figure 8 ‘Kompas’). In the graphical interface the user just mark one of those points and run a separate navigation graphical interface for local control - a compass that leads him to the selected tree. Different positions i.e. the centre of each GERK, position of the tree captured in the past year, are stored in the database.

When moving through the orchard the compass (Figure 8) shows three directions:

- • movement (dark arrow), which represents the direction of movement and still shows up
- • direction north (empty arrow with a red dot), which points towards the north, and
- • direction to target (a bright arrow), which points towards the selected target.

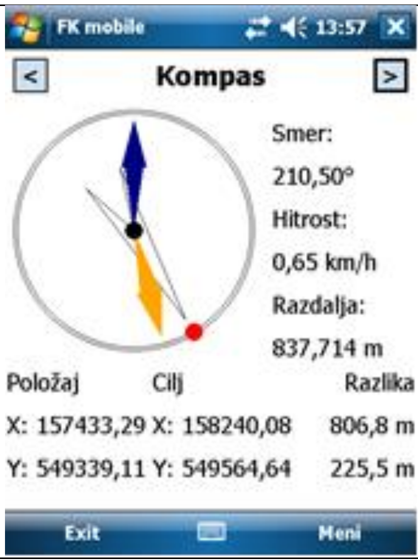

Fig. 8. The graphical interface ‘compass’.

The textual part in the interface shows coordinates for the current situation ‘Položaj’ and the target (‘Cilj’) chosen in Gauss-Krueger D48 coordinates, direction (‘Smer’) and current speed (‘Hitrost’) of movement and a distance to a selected tree ‘Razdalja’), Euclidean distance, the distance in ‘x’ direction and distance in the ‘y’ direction between the current position and the selected destination.

2.8. Experimental lay-out

Since capturing images in the orchard requires a lot of walking, we decided for AMP Huawei Honor 6 Plus, running on Kirin 925 chipset with Octa-core (4x1.8 GHz Cortex-A15 & 4x1.3 GHz Cortex-A7) with built-in GPS receiver, 3GB RAM, two cameras and additional 32 GB memory card, which helps the user to locate and record the tree position automatically.

The operating system was tested in 2017 and 2018 on 245 intensive orchards’ positions (GERK) selected from the register of orchards according to the apple and pear varieties, planting year and growing form. One smaller part of the orchards (43 samples) was growing under the black hail net (Wiesel double-weft 2.9 mm x 8.9 mm, 0.3mm PEHD), which was installed 1.5 m over the trees.

In ten days during the first half of July 2017, each GERK was entered after the GPS global guidance had brought us to plot border. After selecting the required data from the application menu, twenty apple trees were randomly selected and two images of each tree were captured and georeferenced simultaneously. At the same time, a plastic belt was wrapped over the tree trunk, which enables clearly detection of the position in the following year (Figure 9).

Fig. 9. Sample tree with a plastic belt.

In the second year the same sampling trees (positions) were visited again by using the global guiding and ‘compass’ function described in section 2.3. Each time the compass led us to the selected position, so the actual position was compared to the previous year. In all cases both positions differs each other, the 2018 position was georeferenced again to calculate the GPS accuracy later.

After the AMP was connected to the system on the PC and data synchronization was completed, manual comparison between the data stored in an AMP and that from GERK was done in the laboratory. Data error checking was much easier in digital format compared to paper, and the process also avoided translation errors from paper to digital format.

3. The accuracy of AMP location system

The new approach to random selection of parcels and autonomous guidance to orchards for the early forecasting of apple and pear yield was shown to be very efficient and precise. The user-friendly PC application allows easy data transfer from the central databases to the AMP and scheduling daily routes, which is needed for sampling the same trees each year. Directions to a daily path over the AMP and a program for street navigation led us to the selected orchards by the quickest way, which saved considerable time, especially when accessing the plantation without the owners.

However, whenever approaching a particular orchard for the first time, it could happen that without the local producer we were unable to find entry through the fence, since the global positioning guidance is based on the GERK central point, i.e. the centroid. Since the centroid is the intersection of all straight lines that divide border lines into two equal parts about the line, it can be located even on a very steep hill, quite far away from all urban roads, which are recorded on the common GPS maps. Therefore, for preventing disorientation on local roads, it is suggested that the researcher drive to the producer’s address on the first visit.

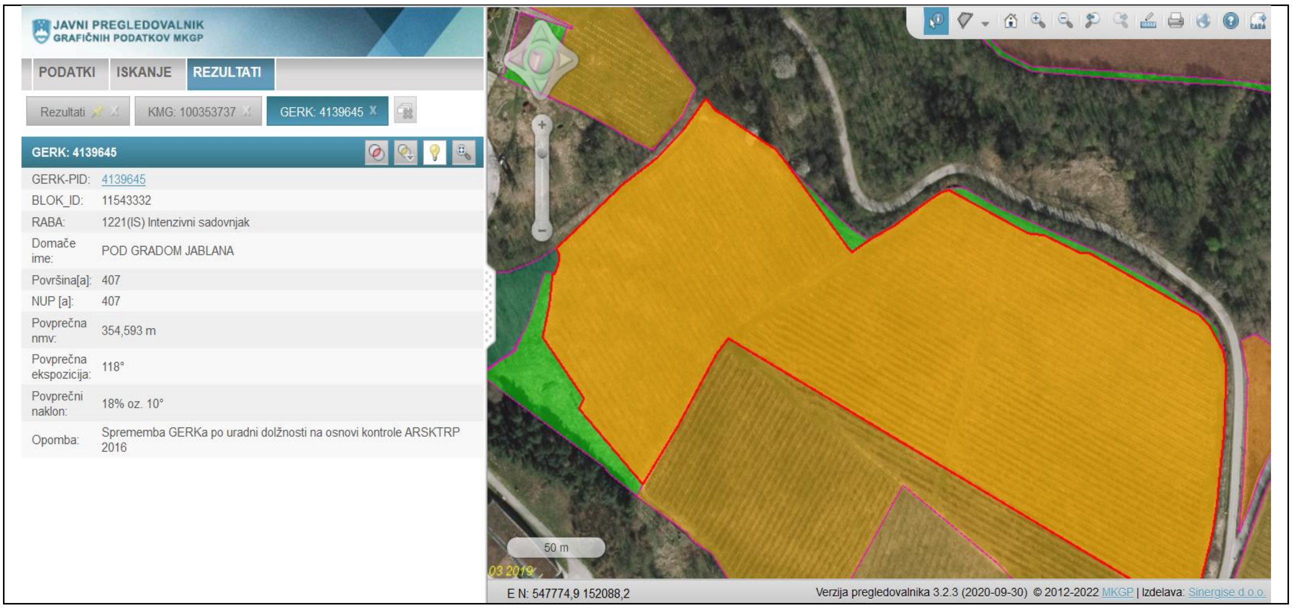

Fig. 10. A sample of GERK together with a centroid and local roads.

The postponed manual comparison between stored data position (x, y) in an AMP and those from GERK base for 2017 showed (Table 1) that in 18 cases (7.35 %) errors of measurements occurred because of incorrect positioning, when the system was unable to locate the user position properly, owing to his standing too close to the border of the GERK unit.

In four cases (1.63 %), on a location with young orchards planted on previous arable land, there was an error in the GERK base due to incorrect data input, so the system did not recognize the orchard but only the arable land. Such register errors were eliminated in 2018 by importing the newly corrected database from the Ministry, so in total all but one from 244 samples were positioned correctly.

It was proved that the main reason for GPS error was PDA GPS device accuracy. In fact, the GPS error is not a real error, but only code specific information. On the other hand the main reason for GPS errors was proved to be the GPS device accuracy which was limited on 10 m. To omit this error, the user was asked to enter over 20 m deep in the GERK and subsequently the accuracy of the system increased on almost 100 % in 2018 as seen in Table 1.

	2017		2018	
	Number of samples	[%]	Number of samples	[%]
Correctly	223	91.02	244	99.996
Register error	4	1.63	0	0.000
GPS error	18	7.35	1	0.0004
Total	245	100.00	245	100.000

Tab. 1. The accuracy of autonomous guiding system (n=245).

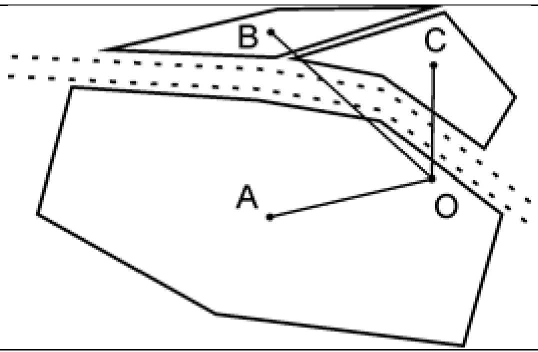

Fig. 11. GERKs and the positions of the user.

4. Summary

This book chapter paper focuses on a system for precise location of trees in the orchard needed for capturing and processing the images for forecasting the future yields of apple or pears. The new approach for random selection of parcels and autonomous guiding into the orchards was shown to be very efficient and precise. Thus, it enables a good basis for more accurate apple and pear yield forecast also between successive growing seasons. The user-friendly PC application allows easy data transfer from the central databases and scheduling daily routes into AMP, which is needed for sampling the same trees each year.

A guideless on a daily path over the AMP and a program for street navigation (Googlemaps) led us to the selected orchards on a quickest way, which saved a lot of time, especially whenever attempting the plantation without the owners.

In 2017 the information on the tree position captured by the image camera was tested on 245 samples (22 apple and 6 pear varieties). Postpone manual comparison between the stored data in a AMP and those from GARK base showed that in 23 cases (9.6 %) errors of measurements occurred due to the incorrect positioning or incomplete data in the GERK base. In 2018 all samples were positioned correctly, so the system can be directly transferred into the practice.

The presented system can easily and quickly detect the position of the sample tree in the orchard, which is being later processing in the laboratory for predicting yield at harvest. The first test in 2017, however, showed that the centroid of the GERK was not enough precise information in 19.6% of samples to locate the position correctly. We expect to improve the algorithm in the next season by introducing the polynomial data of the GERK, which will provide a clear choice of only one plantation.

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