UNIVERSAL GRAIN COMBINE HARVESTERS USED IN THE PRECISION AGRICULTURE SYSTEM

Šumanovac Luka[1], Ban Josip[2], Kiš Darko[1]

[1]Faculty of Agriculture, University of *Josip Juraj Strossmayer* in Osijek,
Department of Agricultural Engineering, H. D.Genschera 16 d, 32100 Vinkovci, Croatia
[2] A student at the Faculty of Agriculture in Osijek
e-mail: lsumanovac@pfos.hr; dkis@pfos.hr

SUMMARY

Grain combine harvesters have been developed through years from narrowly specialized machines to today' universal agricultural machines used for harvesting and picking some of the most important agricultural plants. The seventies mark the beginning of the implementation of complex computer systems used for control, measuring, automatic regulation, and steering of the machine. Computerization and installing of electronics as a part of measuring devices of a combine made it possible to measure the harvested area, to monitor the grain loss and the total yield of the harvested field as well as the particular field parts. In this way it enabled the creation of yield maps for a particular field part according to its yield. Furthermore, the effects of the above mentioned were the frequency and loading control of the important shafts, the control of the combine harvester to achieve its optimum throughput, connection to the satellite navigation, keeping record of failures in order to repair them on time, and collecting the data needed for a well-timed servicing. Large capacity combines are not only provided with the above mentioned features but also with such as follows: the possibility to connect to other computers to get the necessary information; automatic computer steering – the maintenance of the driving route; automatic regulation of the mass flow through the combine; and other features since they are constantly developing and finding their application in new combine types. The biggest achievement so far in relation with the control of combine harvesters is the satellite positioning, which makes it a universally computerized machine generally able to perform other operations based on mapping.

Keywords- universal grain combine harvester; GPS; mapping; positioning; precision agriculture.

1. INTRODUCTION

The combine was patented in 1835 in the USA, which marked the beginning of this machine type. The machine "combined" harvesting, threshing, and cleaning grain plants and all that at one go [1]. Early machines were drawn by horse or mule teams. In 1871 a self-propelled combine harvester was produced and it was powered by a steam engine. In 1938 the first combine powered by an internal combustion engine was introduced [2]. 1954 is an important year in which some redesigns were carried out and the combine was used for removing the ears of corn and finally for the separation of the corn from the ears. Soon after that it was also used for harvesting all kinds of oleiferous plants, bean, pea, grasses grown for seed, sugar beet, and other plants. The production of combine harvesters in Croatia started in 1984 in the factory "TPSU Županja", in accordance with the license issued by the German "Fahr" factory [2]. At the beginning of the nineties there were more than four million combines in the world, based on the FAO data [2]. The number of combines is nowadays decreasing, whereas their capacity is rising. Early combines were used for harvesting grain plants (wheat, barley, oat, rye) with an annual use of approximately 20 working days. The improvements of combines and their wide use in harvesting different plants account for an increased amount of the annual hours ranging from 700-1200 hours. The combine harvester efficiency (capacity or throughput) rose from 2 kg/s in 1950 to 10 kg/s in 1980. At the end of the 20th century it reached up to 19.3 kg/s [2]. The development of modern combine harvesters shows the tendency towards increasing the efficiency by improving the present constructions as well as by developing new ones. This refers to redesign of cutting, threshing and cleaning devices; the implementation of wide tyres in order to preserve the soil; making the combine an even more universal machine; and the application of electronics and telecommunication in control and steering management. Designers also pay due attention to better ergonomic solutions especially in concern with the drivers' position [3,4]. The only prosperous combine harvester market is expected to be found in the developed countries of the USA and Europe due to the fact that combine harvesters are very expensive [5]. The best integrated agricultural machines are combine harvesters [6]. Until the sixties they were provided with only a simple system rendering the information on labour activities and the way of working parts adjustment. The information system comprised only the basic controls guiding engine performance and perhaps a threshing drum revolution counter. Combine adjustments were performed by mechanical means - either when the combine came to halt or when moving. In the latter case they were performed by combine hydraulics. The seventies mark the beginning of more complex computer systems applied to universal grain combines. Automated steering was introduced in order to ease the driver's efforts [7], which is especially the case with wide-cutting combines working at increased speeds. At the same time researches were conducted in order to improve the driver's cab from the point of view of ergonomics. The driver is closed within the cab and he needs as much information as possible to control the performance of the combine. This feature was supplied on account of the development of electronic components and computers [1,6]. The devices control, measure and perform automatic regulation and steering. Controls are used by the driver to indicate certain conditions or failures. Measuring devices register different values (engine power, working speed, threshing drum frequency, grain mass flow, etc.). All the data supplied by the aforementioned devices are used for the regulation of the harvest technology.

2. CONTROL AND STEERING OF A UNIVERSAL GRAIN COMBINE

In order to achieve as successful and humane combine control as possible some electronic component were implemented in combines, which was only very scarce in the beginning. Later more electronic components and computerized devices were implemented to allow for the control over the machine performance and its automatic steering. Controls are maintained by levers, information boards, and computers set in the driver's cab (board PC – different manufacturers use different names for it). Modern computers are provided with a dashboard with a multi-purpose lever and with a computer and monitor able to display much information and also to provide their printed version. The multi-purpose lever can perform the following operations [8]:
- raising and lowering the pickup reel
- moving the pickup reel forward or backward
- raising and lowering the header
- switching the header off/on
- providing the floating position of the header ±150 mm
- adjusting header tables
- adjusting hydrostatics forward or backward.

The computer records information on the memory card, so that it can be processed later on. Based on the input GPS data the computer is also a source of information used for yield mapping and an efficient farm maintenance [9]. Besides the computer there are somewhat simpler systems, which can be used for data storage on a memory card, but which do not permit their printing. During the harvesting and picking of plants a serious problem is the maintenance of the appropriate steering direction of universal grain combines. This refers to wide-row plants such as corn as well as to the correct windrowing maintenance with narrow-row plants (grain crops and similar) [10]. Automatic combine steering which follows the set direction allows for a greater attention of the driver to the working performances of certain combine parts and the combine as a whole. The issue of automatic combine steering in corn harvesting was solved by implementing two contact keys between a pair of crop dividers mounted on the header. If dividers do not follow the middle of the row, a key is bent down due to the stalk weight. This action is detected by a sensor which, in turn, affects the steering modulus by a servovalve. The modulus affects the running wheels, which take a swerve and in this way correct the moving direction [8,10]. Automatic steering of a universal grain combine harvester is more difficult when harvesting grain crops. This is due to the fact that these crops have stalks of lesser stiffness, which consequently do not exert enough force to affect the contact key. Furthermore, the crop is often lodged and the harvest is often perfomed in the transverse direction to the rows. Based on these facts automatic combine steering using the contact key and applied to the grain crop harvest did not yield the expected results [8,10]. The latest technical solution for automatic combine steering was achieved by a laser device [8]. The solution was applied to *Claas Lexion 480* combine harvesters. The device has two laser sensors, which move for 6º to the right or left. The left sensor (transmitter) sends out infrared rays, the frequency of which is 60 MHz. The right sensor (receiver) absorbs the rays which reflect from the stalks or the stubbles. The area of influence of the device is of 14 m of length and 3 m of width. Scan is run three times a second, and the computer works out the optical mean based on the reflection. If the resulting data match the row margins the machine does not change the moving direction. However, if there is a difference hydraulic control responds by correcting the direction either to the left or to the right. The sensors of the laser device not only recognize the crop margin according to its height but also according to the colour, which allows for an efficient use in lodged and weeded crops as well as in night conditions. A laser pilot takes care of automatic combine steering even when it operates at its full working width, which is especially important with universal grain combine harvesters performing large-width operations (above 6 m) and which are most often affected by the reduction of working ranges [8].

3. MEASUREMENT OF HARVESTED AREA

Board monitors can also be used for the measurment of the actual combine harvested area. This is possible on account of the following information [11]:
- measurment of the travelled distance
- determination of the operation width of the machine

- determination of the active working hours spent combining.
Based on these the following data could be derived [11]:
- the size of the harvested area
. the total harvested area (the sum of single results)
- working time spent in a particular area
- total harvest time (the sum of single results)
- the moving speed of the combine
- the total distance travelled.

The measurment of the harvested area is possible by a computer set in the driver's cab and a revolution sensor detecting the revolution of running wheels [12]. The following data are entered into the computer: the circumference of the wheels and the average wheel slippage, the header width and the working hours of the machine. The size of the harvested plot can be computed by multiplying the travelled distance by the header working width. If there is no device which monitors the header operating width, then in order to overlap the travelled rows the operating width is reduced by 10 %. The combine speed is the distance divided by the time. The calculations are performed by the computer and the driver has the data available according to his needs. The computer registers real-time information, but it can also register it on a daily or seasonal basis. Nowadays we have the devices [12] which can both register the header working width and also automatically steer the combine with as small a windrow overlapping as possible. This permits the driver to take better control of other combine components. One of them is the laser sensor which records the surface underneath. This device enables [12,13] a more efficient exploitation of the header working width, a more precise calculation of the harvested area and yield. There are also such devices which register the combine working hours by switching on when the combine is working, and switching off when it comes to halt.

4. YIELD DETERMINATION

An important problem is the determination of local yield. The yield can be measured on large and small areas (local yield). When measuring the local yield the following failures are likely to occur [14]:
- in concern with a precise determination of the surface efficiency
- in concern with positioning-locating the area where the yield measuring takes place
- in concern with analyses and yield mapping.

The above mentioned failures are mostly due to the type of a measuring device and its way of work, but also to the calibration failure of the device. Yield determination from larger areas is possible by weighing the stored grains. They used to weigh the trailer which was loaded with grain harvested from a particular area, which turned out to be impractical. Another way to weigh grain was made possible by the design of a combine tank as an electronic scale, which displays the present grain amount on the monitor. A simpler way is to weigh the grain content in the trailer designed as an electronic scale with an in-built reloader. Both methods are impractical [11], although they can provide precise information related to the yield from a particular area. Recently it has been made possible to incorporate measuring devices on the transporter, in which case the yield measuring is performed either when loading the grain tank or discharging it. This way allows for a continuous yield determination from small areas, as well as the determination of the total yield from a whole area. Numerous devices are for the continuous yield determination. They are either a part of the standard equipment, or they can be implemented as additional equipment. The devices function basically on the principle of volume determination (yield determination based on the hectolitre mass). Another way is flow and grain mass measuring [1,11]. The results of continuous yield measuring can be entered into a yield map, Fig. 2, which shows a conspicuous yield variability of the area. Based on the yield amount, you can create an account of nutrients absorbed from a field by the plants [9,11]. In the last two years devices have been implemented functioning on the photocell principle used for yield measuring during harvest [15].

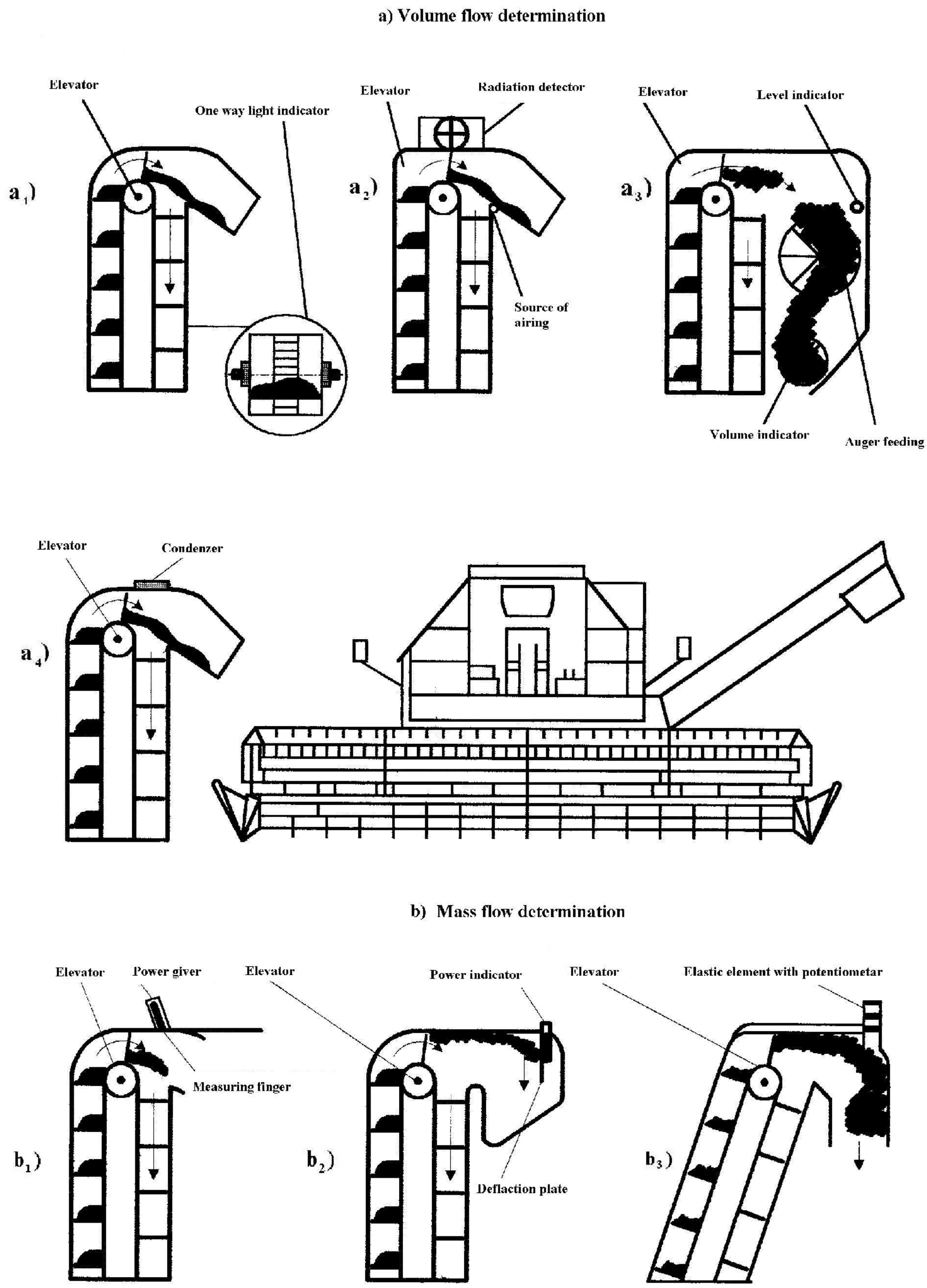

Figure 1. Systems for continual crop yield volume and mass flow determination

4.1. Measuring based on volume

You can find different types of systems [11]:

- measuring performed at the end of the grain auger; in this case yield measuring is done by the revolution resistance determination of the grain auger and by calculating the hectolitre mass

-*Yield-o-meter* device manufactured by the *Clayton* factory was designed in the eighties. It consists of a volume metre set at the end part of a chain transporter. When the barrier is loaded with grain, the grain level metre turns on the wheel, which discharges, and when it is empty the wheel, in turn, stops revolving and the tank gets loaded

again. Grain flow is measured by the wheel revolution number, the wheel tank volume, and the mass in hectolitres.
-*Ceres-21* appeared on the market in 1993. The device is incorporated within the transporter, which conveys grain to the tank. Light rays are used for measuring (one-way light indicator). The grain height is determined in the transverse direction to the elevator slat. It is followed by the volume determination.
Universal grain combines *Claas Lexion* are provided with a yield measuring device known as *Quantimeter* [15], which measures the flow of threshed grain, and grain humidity, and it displays the processed data using either the *CEBIS* or *IMO* systems, or by an *ATC* board computer. The device works on the principle of photocells, i.e. it uses photocells for measuring of the transported grain by a particular elevator vane (volume measuring). Precise data concerning the flow, yield, amount and humidity of grain can be achieved by the application of certain correction factors, among which the longitudinal and transverse combine inclination
John Deere combine harvesters series 9000 and 2000 are provided with the *Green Star* measuring device [16]. It also exploits the volume principle, i.e. it counts the grains by the flow sensor, which has the form of a sensitive plate located on the transportation elevator top, which conveys threshed grain. A minor calibration gives the measuring precision of 97-98 %. The device is equipped with a special sensor which measures the present humidity of threshed grain.
The research of particular measuring devices operating on the volume principle proved that the best results were obtained by the *Class* factory device using photocells [8].

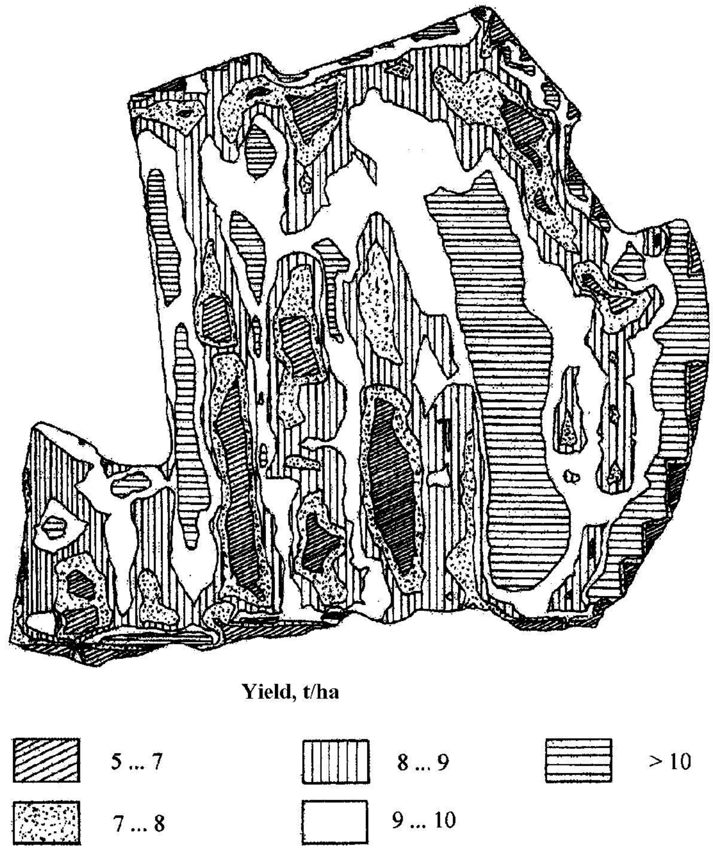

Figure 2. Crop card

4.2. Yield measurement based on mass flow
There are some systems exploiting this principle [11,12] :
- at the beginning of the nineties the *Massey Ferguson* factory started using the *Flow Control* device. It operates on the principle of a radioactive radiation bundle coming from a weak source-americium isotope (*Am*) 241. The radiation source is located under the transporter head used for grain lifting. A radiation measuring detector is located on the opposite side of the radiation source. As the grain flows the radiation decreases. The difference between the transmitted and received radiation is in proportion with the amount of the flowing grain. The driver can read the amount of the flowing grain. It is a low intensity radiation and it is not possible to measure it even

from a distance of 20 cm. The grain radiation is lower than the radiation the grain receives from the air in a period of time of 20-30 minutes.
There are also some devices which measure the flow based on force or impulse determination, in which case appropriate sensors are installed. Force is measured either by take-up rollers or bent sheet plates with incorporated sensors.
- *Grain-Trac* is provided with two take-up rollers used for measuring the grain impact force. The device can be built into all types of universal grain combine harvesters.
- *Yield - Monitor LH Agro 565* has a buffer plate set under the right angle to the direction of grain discharge
- elevator speed is calculate on the basis of the elevator revolution, whereas the force is measured by the force sensor located on the board. All combine types can be provided with these devices.
Grain mass flow measurement is done by a flow scales and a sensor located at the outlet part of the transporter.

5. SATELLITE POSITIONING OF A UNIVERSAL GRAIN COMBINE

The global positioning system enables location and navigation independent of time and position [17]. It is used in agriculture, among others, and it is especially used in developed countries. In the last twenty years two almost identical systems have been developed and they are the GPS (*Global Positioning System*) and *Glonass*, which was developed in the former Soviet Union [11]. These systems consist of several segments. First of all, they include the earth segment and the control segment. The space segment consists of 24 satellite units, which travel round the Earth following the set paths at the app. height of 20,000 km. The user segment consists of a satellite signal receiver. It can be used on the firm ground, water, or in the air, with the number of users being unlimited. The application of the positioning system at a farm can be various [18]. A minor requirement is made by transportation vehicles which are in use on remote fields. A more serious requirement is the use of GPS as a information and documentation source for the management of local activities of machinery (e.g. grain combines with high efficiency). Recently a differential system for satellite positioning has been in use (DGSP) [14]. This system contains two parallel receivers, and one of them is located at a well known position. It determines the position of the other receiver using its own position in relation to the satellite, and it sends signals to the other receiver (failure correction). Fig. 3 is a scheme of a global positioning system [19]. Today's DGPS precision meets most of the present requirements in relation with the provision of the documentation and navigation of a grain combine. The area where a failure occurs can be automatically detected with a precision failure of up to 1% [19,20].

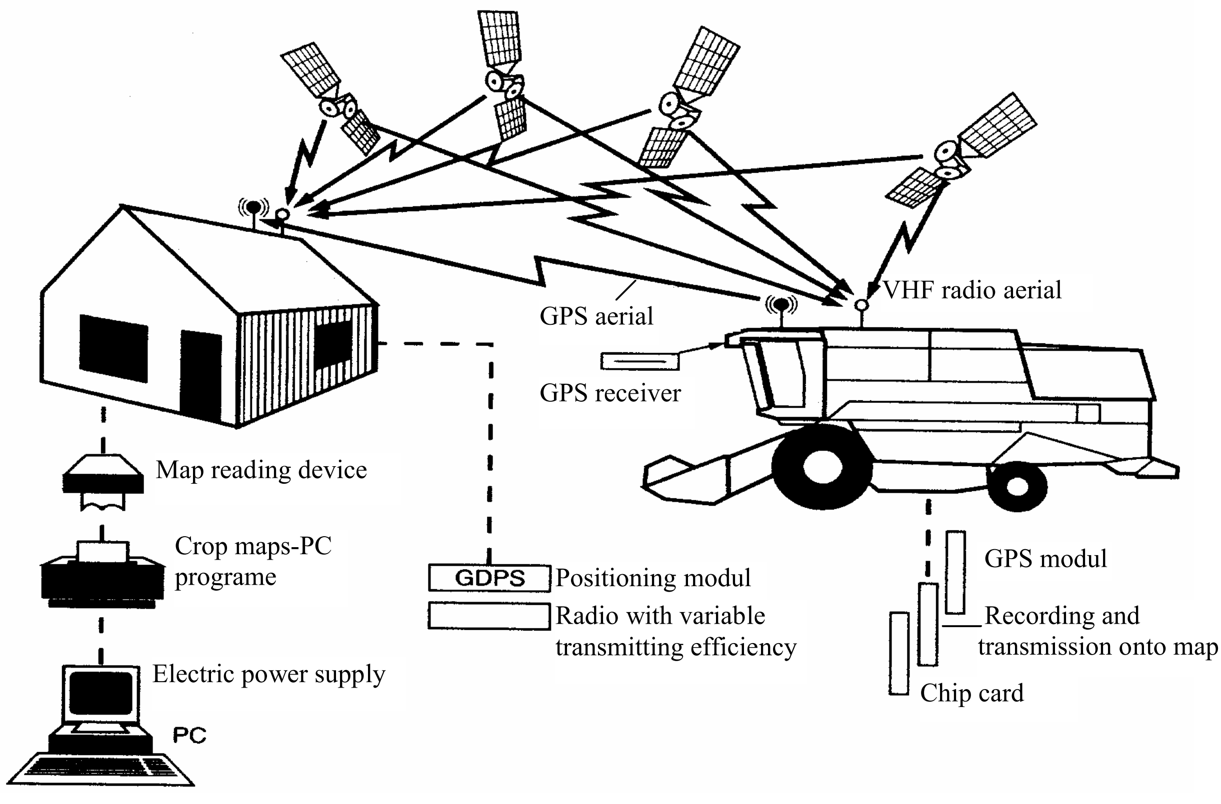

Figure 3. Global positioning system on the example of a combine harvester [7]

An analysis of working hours can be conducted in order to determine the surface efficiency for each plot. In this case the data concerning the total processed area and the time spent are used. Fig. 4 shows the trajectories of a universal combine harvester. The positioning service [11,21] should become an independent organization, which should provide all the system users with the information needed. A universal and low-cost GPS application would be possible beyond the present limits, when this has been verified by ISO standards. When you use the GPS you can find automatically available data in relation with any condition or item present at a farm, and they link to other sources in a satisfactory way. This is the reason why the farm maintenance can benefit from this system [14,22].

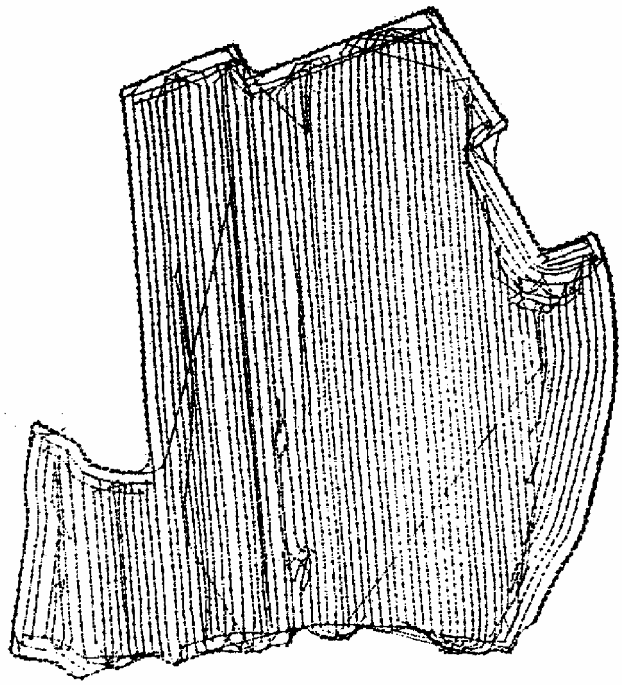

Figure 4. Schematic review of combine harvester trajectories [16]

The GPS system is the basis of precision agriculture, which is only in its beginning in Croatia. Furthermore, the Navstar satellite navigation system is very efficient, especially due to a very simple way of universal grain combine harvester positioning [23].
There are three area of interest where this system can be applied:
- in control, steering, and adjustment of agricultural machinery
- in agricultural machinery maintenance
- in agrotechnics.

Each plot has its specific features, especially when designing application maps. You cannot use a single yield map to create an overall application map for fertilization and plant protection [23,24]. The presently used algorithms are not complete and should be improved. The future development will focus on the creation of optimum technical solutions enabling a more efficient use of application maps. The computer should figure out the machine position in the real time based on the input data as well as the previously stored data [23]. Therefore an intelligent revision of operational data should proceed.
A new differential global positioning system in the real time with a precision of 1 cm was designed at the Hohenheim University and it can be use for the automatic combine steering [25].
The combines in Croatia are very rarely equipped with computer measuring devices, and they hardly have the equipment needed for satellite navigation [26]. An exception are *Claas Lexion*, *John Deere 9780 CTS* and *Đuro Đaković Globus 6.240 H* combines. A 2002 survey showed that these devices were not used during the harvest. The devices, except the grain loss detector, were not used due to the lack of knowledge of the drivers, as well as due to difficulties of surveillance and adjustment of numerous control and measuring combine systems. The market price of a mapping device is high – 11,500 €. The market price of the aforementioned devices is in the range from 7,000 to 17,500 €. Despite this we think that implementation of new computer systems, yield mapping, and similar are very favourable for combine performance. Based on foreign experience we can say that these devices help develop the full capacity of a combine. The application of a positioning system makes a combine a completely computerized machine displaying great operational and mapping precision.

6. CONCLUSION

Manufacturers of universal grain combines and other agricultural machinery which has in for the last twenty years have greatly exploited the potential of electronic equipment built in combines. The goal is to get a highly sophisticated computerized system to allow for a safer and automatic steering. The system provides a wide range of information for a safer and easier combine surveillance. Furthermore, it enables the machines to operate at increased speed rates preserving the high level of the working quality as well as increased efficiency, and the possibility of the use of satellite navigation. This paper presents some devices and systems which are installed to universal grain combines. First of all it is a board computer, which lets you feed the information into your PC and make further analyses. Then, we should point out to the measuring system for a harvested area as well as the system for yield measuring. A satellite positioning is of interest, too, as well as yield mapping for small plots. Finally, we can mentioned the robotized operations performed by a universal grain combine. We do not use robotized combines in Croatia, which means that more efforts should be made in relation to this issue.

7. REFERENCES

[1] Brkić, D., Vujčić, M., Šumanovac, L.: Machines Used for Harvesting and Picking of Grain Plants, The Faculty of Agriculture in Osijek, Vinkovci, 2002, pp. 116-122.

[2] Čuljat, M.: Agricultural Machinery as the Basis of Precision Agriculture, A Collection of Papers from the 26 International Symposium on the Present Tasks of Agricultural Machinery, Opatija, 1997, pp. 11-19.

[3] Kutzbach, H.D.: Mähdrescher neue Entwinklungen 1992, Landtechnik 10, Darmstaft, 1992, pp. 492-493.

[4] Kutzbach, H.D., Wacker, P.: Mähdrescher. Neue-und Weiterentwicklung, Landtechnik 6, Darmstadt, 1995, pp. 320-321.

[5] Kutzbach, H.D., Wacker, P.: Mähdrescher. Technischer Standt und trends, Landtechnik 6, Darmstadt, 1992, pp. 320-321.

[6] Čuljat, M., Barčić, J.: Agricultural Combine Harvesters, The Institute of Agriculture in Osijek, Osijek, 1997.

[7] Eichorn, H.: Landtechnik, 7. Auflage, Verlag Eugen Ulmer GmbH & Co., Stuttgart (Hohenheim) 1999, pp. 13-16.

[8] Vojvodić, M.: Combine Harvesters, Nevkoš, Novi Sad, 2002, pp. 98-106.

[9] Auernhammer, H.: Combine Harvester-A Source of All Information, Agrotehničar 1-2, Zagreb, 1995, pp. 8-10, (translation).

[10] Stoll, A.. Kutzbach, H. D.: Integration of GPS Guided Machinery and Automatic Path Planning, A Collection of Papers from the 31 International Symposium on the Present Tasks of Agricultural Machinery , Opatija, 2003, pp. 103-114.

[11] Demmel, M. Auernhammer, H.: Application of Satellite Positioning in Agriculture, Agronomska saznanja 3-4, Novi Sad, 1998, pp. 69-78, (translation).

[12] Tešić, M.: Agritehnica 1999.–Fair event and new products, Agronomska saznanja 3-4, Novi Sad, 1998, pp. 40-44.

[13] Auernhammer, H.: Elektronik in Traktoren und Maschinen, BLV Verlagsgellschaft mbH, München, 1991.

[14] Hirt, C.: Das Landwirtschaftliche Kommunikationssystem (LKS), Österreichisches Kuratorium für Landtechnik und Landentwicklung, Wien, 1995.

[15] Kutzbach, H. D.: Mähdrescher-Combine harvesters, Jahrbuch Agrartechnik-Yearbook Agricultural Engineering, Band 15, VDMA Landtechnik, VDI-MEG, KTBL, Frankfurt, 2003, pp. 147-154.

[16] …John Deere 9780 CTS Combine Harvester, A Brochure by John Deere agricultural machinery factory, Mannheim, 2003, pp. 1-16.

[17] Speelman, B.: Precision Agriculture, Landtechnik 3, Darmstadt, 1997, pp. 158-160.

[18] Jurišić, M., Hengl, T., Bukvić, Ž., Brkić, D., Kralik, D.: Geoinformation technologies in agriculture, A Collection of Papers from the 27 International Symposium on the Present Tasks of Agricultural Machinery, Opatija 1999, pp. 35-40.

[19] Brkić, D., Šumanovac, L., Jurić, T., Knežević, D.: Tendencies of the Development of Universal Grain Combine Harvesters, Strojarstvo Vol. 43 1-3, Zagreb, 2001, pp. 41-48.

[20] Jurišić, M., Hengl, T., Šumanovac, L., Kralik, D.: Agro–ecological Modelling in GIS Environment, A Collection of Papers: Limnological reports, Vol. 33, Proceedings of 33rd Conference, Osijek, 2000, pp. 527-533.

[21] Demmel, M., Auernhammer, H.: Automatisierte Prozeßdatenerfassung Elektroniekeinsatz bei der Zuckerrübenernte, Landtechnik 3, Darmstadt, 1998, pp. 144-145.

[22] Hengl, T., Brkić, D., Bukvić, Ž., Jurišić, M.: Possibilities of Application of Remote Researches, Satellite Navigation, and GIS Technology in Agriculture, Poljoprivreda 4, Osijek, 1998, pp. 103-111.

[23] Scheufler,B.: Intelligente Technologien im Landmaschinenbau, Landtechnik 6, Darmstadt, 2001, pp. 396-397.

[24] Tiessen, E.: Variabilität der Teilflächen bei der sensorgesteuerten Stickstoffdüngung, Landtechnik 4, Darmstadt, 2002, pp. 208-209.

[25] Kutzbach, H. D.: Efficient Crop Harvest, A Collection of Papers from the 28 International Symposium on the Present Tasks of Agricultural Machinery, Opatija 2000, pp. 11-23.
[26] Ban, J.: The Tendencies in the Development of Agricultural Machinery at the Beginning of a New Millenium (a B. Sc. thesis), The Faculty of Agriculture in Osijek, Vinkovci, 2005.