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Analysis of Process Modeling in Modern Software Program to Support "Smart" Agriculture

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The modern level of development of computer technology and software has created the prerequisites for a new approach used in the precision farming system. One of the priority areas is the use of modern software products that are based on the use of computer simulation models that allow performing crop yield forecasting modeling, including approaches to differentiated fertilization and minimizing negative environmental impact. The purpose of this work is to analyze and substantiate the main effective software modules, which are based on the integration of meteorological indicators, satellite measurements of spectral parameters of agricultural crops, statistical data on crop yields for a certain period and satellite images, allowing you to create dynamic predictive models aimed at solving the problem of managing technological processes in the offline and online modes. Based on a comprehensive analysis of modern GIS software products, the main modules were identified and a technological scheme for integrating input data and their subsequent processing was proposed: creating a yield map, planning, according to weather conditions, sowing dates, the ability to prepare tasks for differentiated application of fertilizers and plant protection products, conducting statistical analysis of harvesting data, planning sampling points for agrochemical examination and subsequent accounting of the results. These processes will be implemented through the geoinformation application "Agronomist's Tablet".

1. Introduction

The defining characteristic of "Smart" farming is the use of technology for better crop planning and management. "Smart" agriculture includes the use of satellite images to determine soil characteristics, monitoring plant development and yield assessment, as well as the analysis of weather data for crop management and the use of unmanned aerial vehicles and high-tech combines (Tao et al., 2021). Armed with these tools, producers will be able to independently develop more efficient farming methods, such as the precise use of agricultural chemicals - pesticides and fertilizers, saving time and energy while increasing yields. Today, the market of goods and services offers a wide range of specialized software applications for agriculture: ExactFarming (Russia) (2022), OneSoil (Ukraine) (2022), Egistic (Kazakhstan) (2022), GIS Panorama AGRO (Russia) (2022), Cropwise Operations (Ukraine) (2022), Scoutpro (USA) (2022), Farmathand (Canada) (2022), Pessl Instruments (Austria) (2022), etc. The modern methods of information processing used in these applications in the development of sound recommendations for managerial decision-making by agricultural specialists are based on the analysis of multiple factors affecting production efficiency, and their integration with various intelligent IT applications that process data in real time. At the same time, the usefulness of recommendations for specialists increases with the growth of the number of users connected to a single network and exchanging data through cloud management services for agricultural enterprises. This software is based on the geoinformation system belonging to the class of ERP systems. They are intended for agricultural managers of crop farming enterprises, managing farms using precision farming technologies, and include the following main

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modules: maps and schemes of plots, land management, yield mapping, documentation, GIS and raster maps, remote maintenance by means of Internet technologies (Jha et al., 2019).

For example, the online field monitoring and agricultural management service developed by ExactFarming (2022) determines weather data, vegetation index, crop rotation status over the past years, soil fertility, reflects the progress of fieldwork, and information about products in warehouses, and increases the accuracy of risk forecasting. The OneSoil (2022) platform includes Precision Insights tools and API for business, allows you to create maps of field productivity zones for sowing and differentiated fertilization, and includes crop rotation planning. The applications GIS Panorama AGRO (2022), Cropwise Operations (2022), Farmathand (2022), and Egistic (2022) solve the problems of accounting, optimization of agricultural work planning, yield forecasting, monitoring the progress of agricultural work in real time, evaluation of deviations from the plan and the reasons affecting the results. To develop management decisions in the field of agricultural production, these applications have developed a cloud geoinformation and analytical service that provides specialists with information about the state of each field in a certain period and allows them to predict the dynamics of plant development. An example of integrated solutions for smart agriculture is the developments of Pessl Instruments (2022), which help farmers make more informed decisions to optimize the allocation of resources (seeds, water, fertilizers, etc.), make fields more resistant to agricultural risks, optimize tasks using a wide range of wireless, solar-powered Internet of Things (IoT) systems (Jayaraman et al., 2016) for environmental and weather monitoring (Mekala et al., 2019). All data is stored, analyzed, and provided on the Field Climate online platform.

Research and analysis of domestic and foreign applications used in agriculture have shown that the main task of applications for farmers is to use a database based on the integration of various indicators (meteorological, satellite, statistical, agrochemical, etc.) (Yin et al., 2021), allowing to create dynamic predictive models (Wolfert et al., 2017) aimed at solving the problem of managing technological processes. However, analysis has shown that many foreign applications are focused on their natural and climatic conditions. Therefore, it is difficult to use on the territory of Kazakhstan. The development of the geoinformation application " Agronomist's Tablet " will allow you to create a simulation model of crop yield forecasting focused on the natural and climatic conditions of Kazakhstan, which will increase the productivity of agricultural production.

2. Development of modules for the geoinformation application "Agronomist's Tablet

2.1 Choosing the tools

Based on the analysis of applications used for the development of smart agriculture, the task was to develop modules that will form the basis of the geoinformation application " Agronomist's Tablet". For this purpose, the software and hardware methods were studied and analyzed to develop all the tools and functionality of the various applications. As a result, the following tools were chosen:

- JavaScript library - ReactJS (ReactJS, 2022). This library is open-source for the development of user interfaces. The main advantages of this library are high speed, availability and scalability.
- Hypertext markup language HTML (HTML, 2022) and cascading style sheets CSS (CSS, 2022).
- Node.js software platform (Node.js, 2022) will be used as the server part of the application.

2.2 A conceptual architecture of the application

The next step was to develop modular clusters of input and output data for the multi-level geoinformation platform "Agronomist's Tablet". These include:

- Data entered manually by the user: data on agricultural fields, work carried out in the fields, yields, and crop rotations.
- Data obtained using third-party API services:
  - OpenWeatherMap (2022) is an online service that provides an API for accessing current weather data, forecasts and historical data. Official meteorological services, data from airport weather stations, and data from private weather stations are used as data sources. The information is processed by OpenWeatherMap, after which, based on the data, a weather forecast and weather maps are built, for example, cloud cover and precipitation maps. Based on the correlation of two weather services VENTUSKY and WINDY, the module provides more accurate meteorological data for a certain area. These meteorological indicators can be used in planning and conducting fieldwork.
  - SentinelHub (2022) is an online service that provides the latest satellite images from all Sentinel satellites: Sentinel-1 radar images, Sentinel-2 optical multispectral images, as well as Sentinel-3 Earth surface data for joint environmental analysis with data on the atmosphere and air quality in Sentinel-5P.
  - Also, the search and acquisition of satellite images were carried out from the EO Browser website (2022), which is in the public domain. The study used the results of processing satellite data obtained

using the Leaflet API (2022) and the Sentinel hub API for the period from 2017 to 2021, which were used to obtain weekly NDVI index values for the calendar year, calculated from the mask of arable land. NDVI maps allow you to determine the current state of cultivated and weed plants in the fields.

- Data of agrochemical analysis of the soil, the results of which establish the presence of useful nutrients in the soil and the toxicity of the soil. The full list of tests is specified depending on the needs of the farmer. Chemical analysis makes it possible to establish the biological properties of soils, their chemical composition, and obtain information about the processes occurring in the soil. The information obtained is used to determine the state of depletion of the soil, the level of pollution. This information allows you to determine a set of measures to improve the beneficial properties of the soil.
- According to obtained information, data synthesis is performed, taking into account soil-climatic and agricultural conditions using the Python programming language in the Jupyter Notebook development environment (Figure 1) using additional software packages matplotlib (Hunter et al., 2019), pandas (Pandas, 2022), numpy (NumPy, 2022).

```
In [ ]:
from scipy.stats import pearsonr
import math
year = "2017-2021"
FILE = '../Сводная вегетация.xlsx'
SHEET = str(year)
sns.set(rc={"figure.figsize": (30, 20)})
sns.set_style('white')
sns.set_palette('Greens_r')

df = pd.read_excel(FILE, sheetname=SHEET, header=1)

NDVI_COLUMNS = [col for col in df.columns if 'неделя' in col]
CULTURE_COLUMN = 'Культура ' + SHEET
Land_COLUMN = "Поле"
YIELD_COLUMN = 'Урожайность, т./га.'


df_cultures = df[NDVI_COLUMNS]

df_cultures = df_cultures[df_cultures.columns[::-1]]
df_cultures = df_cultures[df_cultures.columns[:52]]

df_cultures.columns = range(1, 53)
df_cultures = df_cultures.apply(lambda x: x.T.interpolate(method='linear'), axis=1)
df_cultures = df_cultures.apply(lambda x: x.fillna(x[x.first_valid_index()]), axis=1)



xt = range(1, 53)

def rmsDifference(a, b):
    rmsdiff = 0
    for (x, y) in zip(a, b):
        rmsdiff += (x - y) ** 2  # NOTE: overflow danger if the vectors are long!
    return math.sqrt(rmsdiff / min(len(a), len(b)))

crops = df[CULTURE_COLUMN]
df_cultures_size = len(df_cultures)
counter = 0;

min_dist_global = 9999999
curve_global = 0
row_gloval = 0
for i in range(0, df_cultures_size):
    min_dist = 99999
    row = df_cultures.iloc[i]
    best_cult = "1"
    for cult in fitted_lines:
        error = rmsDifference(row, fitted_lines[cult])
        #r_row, p_value = pearsonr(row, fitted_lines[cult])
        if error < min_dist:
            min_dist = error
```

```
In [140…
sns.set(rc={"figure.figsize": (20, 10)})
sns.set_style('white')

label_ax = [0] * 6
plot_ax = [0] * 6

label_ax[0] = plt.subplot2grid((4, 6), (0, 0))
label_ax[1] = plt.subplot2grid((4, 6), (1, 0))
label_ax[2] = plt.subplot2grid((4, 6), (2, 0))
label_ax[3] = plt.subplot2grid((4, 6), (3, 0))

plot_ax[0] = plt.subplot2grid((4, 6), (0, 1), colspan=2)
plot_ax[1] = plt.subplot2grid((4, 6), (1, 1), colspan=2)
plot_ax[2] = plt.subplot2grid((4, 6), (2, 1), colspan=2)
plot_ax[3] = plt.subplot2grid((4, 6), (3, 1), colspan=2)

label_ax[4] = plt.subplot2grid((4, 6), (0, 3), rowspan=2)
label_ax[5] = plt.subplot2grid((4, 6), (2, 3), rowspan=2)

plot_ax[4] = plt.subplot2grid((4, 6), (0, 4), rowspan=2, colspan=2)
plot_ax[5] = plt.subplot2grid((4, 6), (2, 4), rowspan=2, colspan=2)

for i in range(4):
    culture = translate[le.inverse_transform(cult15[i])]
    label_ax[i].text(0.3, 0.5, culture, fontsize=18)
    label_ax[i].get_xaxis().set_visible(False)
    label_ax[i].get_yaxis().set_visible(False)

    df_diff_cult = df_diff[df_diff['culture'] == cult15[i]].groupby('week').mean()
    ndvi = df_diff_cult['ndvi']
    ax = plot_ax[i]

    ndvi.plot(kind='bar', ax=ax, color='#4baf9c')
    ax.set_ylim([-0.3, 0.3])
    ax.axes.get_yaxis().set_ticks([-0.2, 0, 0.2])
    ax.tick_params(labelsize=14)

    ax.get_xaxis().set_visible(False)
    ax.get_yaxis().set_visible(False)

for i in range(4, 6):
    culture = translate[le.inverse_transform(cult15[i])]
    label_ax[i].text(0.7, 0.5, culture, fontsize=18)
    label_ax[i].get_xaxis().set_visible(False)
    label_ax[i].get_yaxis().set_visible(False)

    df_diff_cult = df_diff[df_diff['culture'] == cult15[i]].groupby('week').mean()
    ndvi = df_diff_cult['ndvi']
    ax = plot_ax[i]

    ndvi.plot(kind='bar', ax=ax, color='#4baf9c')
    ax.set_ylim([-0.3, 0.3])
    ax.axes.get_yaxis().set_ticks([-0.4, 0, 0.4])
```

Figure 1: Handling Input in the Development Environment - Jupyter Notebook

As a result, the user receives output information, including recommendations for improving soil fertility, yield forecast, and economic efficiency. The interaction of all data and services is shown in Figure 2.

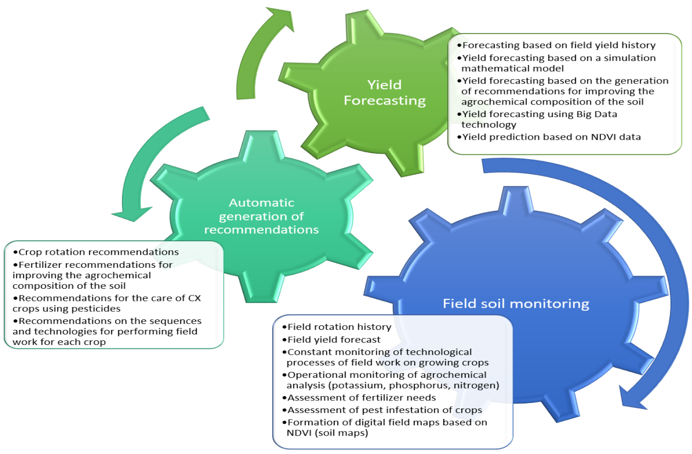


Figure 2: Classification of functionality in accordance with the information needs of consumers of the geoinformation portal "Smart" agriculture

According to the work carried out, a technological chain of business processes in a field of cultivation of agricultural crops was developed. In this chain, agrochemical analysis is presented as the initial data on the basis of which the process of analyzing and calculating yield estimates is carried out (Figure 3).

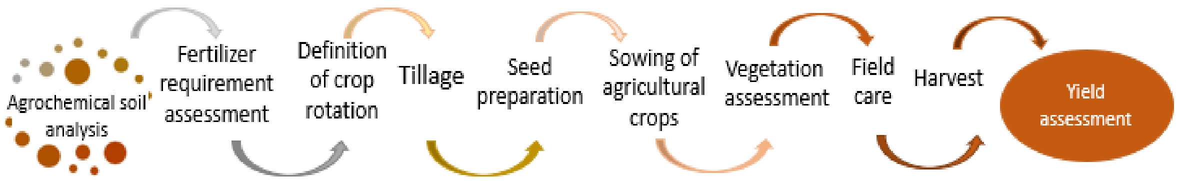


Figure 3: The chain of technological business processes of field work on growing crops

The result of the work carried out is the developed functionality of the geoinformation portal of “Smart” agriculture (Figure 4).

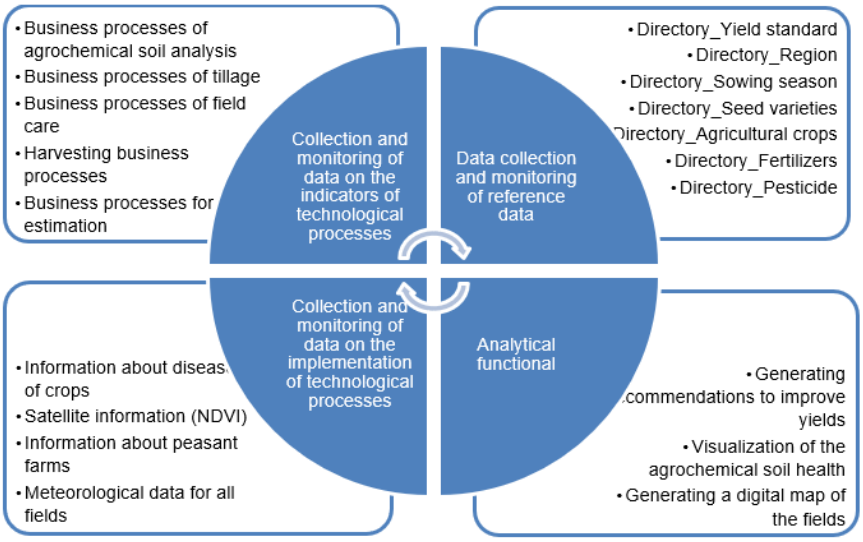
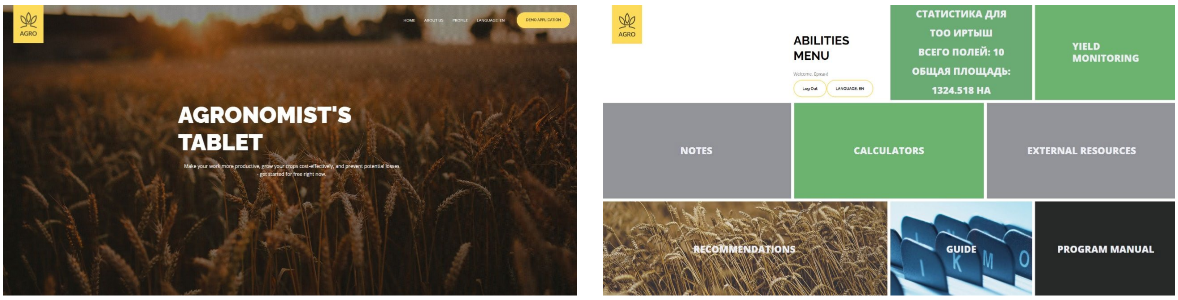


Figure 4: The main functionality of the system

Based on the developed models, the development of the GIS application “The Tablet of Agronomist” began, through which the website (business card) of the geoinformation portal “Agronomist's Tablet”, presented in Figure 5a, was originally developed.

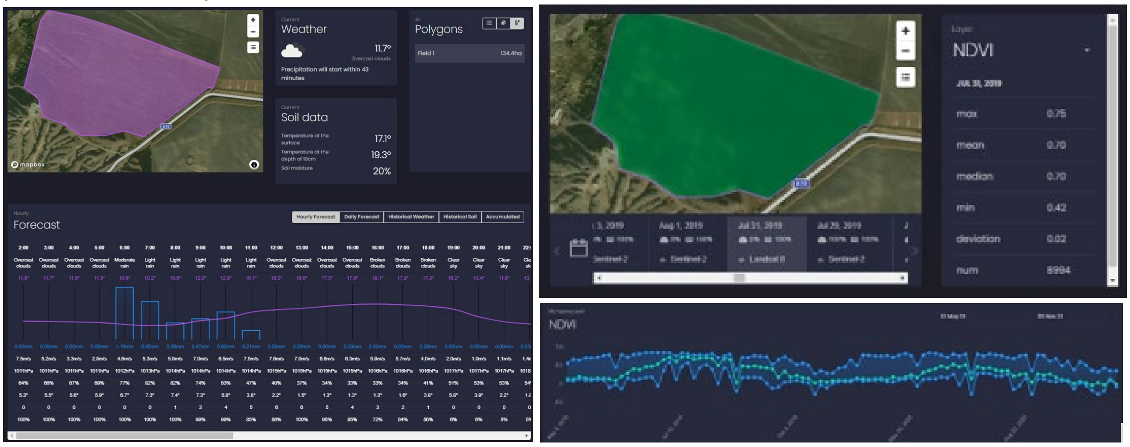


a) b)

Figure 5: The main page (a) and a web-page of possibilities (b) of geoinformation portal of “Smart” agriculture

The developed set of modules is located in the tabs of the web page “Menu of possibilities” (Figure 5b). This menu contains modules such as: calculation of fertilizer application rates, map, calculators, analyses, monitoring of meteorological data, recommendations, reference books, user manual and also the admin panel. Several large agricultural enterprises specializing in crop production participated in the testing of this application. For this purpose, initially, the enterprises were given access to enter data on their fields for several years, data of agrochemical analysis of soils and other necessary information. Based on the entered data, taking into account meteorological indicators for a given territory, the developed modules of the geoinformation application allow creating of crop yield forecast models, carrying out integrated control of production, and providing recommendations for differentiated fertilizer applications.

For example, based on the constructed maps of vegetation indices for the experimental fields of the farms (Figure 6 a), agronomists conducted timely monitoring of the fields, timely identified problem areas, and planned the terms of differentiated fertilizer application. Based on the maps of meteorological indicators (Figure 6b), the farms planned the stages of works in the field season, and determined the optimal timing of works. As a result, costs (fuel, fertilizers) were significantly reduced compared to the previous year by 10 %. Application of integrated approach to planning and conducting field works on experimental fields based on recommendations (Figure 7), formed taking into account farm database and yield forecasting models allowed farms to increase yield up to 8 % (LLP "PFOP", peasant farm "Mayak", EKR). The analysis of the use of the geoinformation application "Agronomist's Tablet" shows the effectiveness of its use in the management of agricultural production of enterprises.



а)　　　　　　　　　　　　　　　　б)

Figure 7: Map of meteorological indicators (a) and NDVI map (b) on the territory of the "Mayak" peasant farm

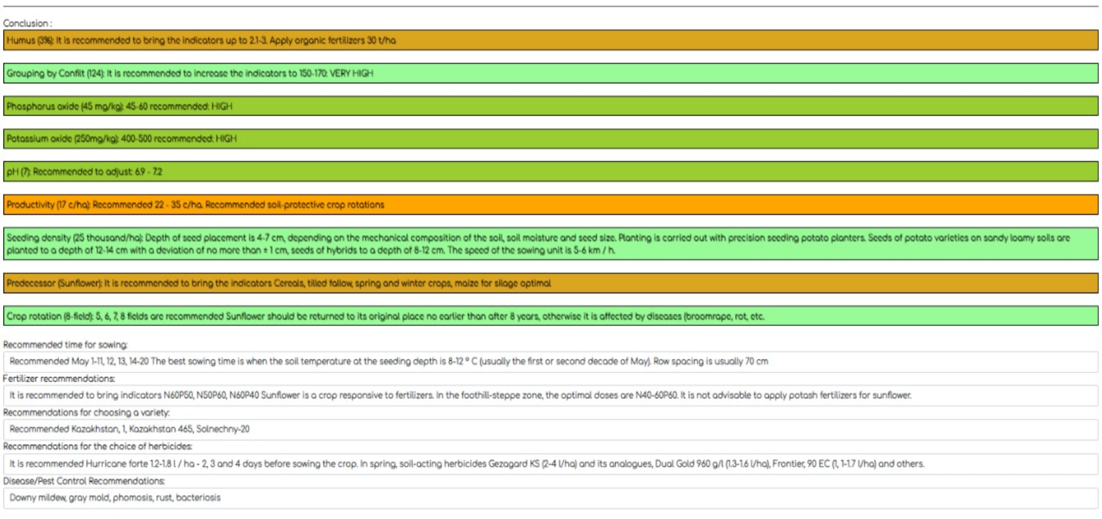


Figure 8: A fragment of the provision recommendations for the farm "Mayak

3 Conclusion

Analysis of domestic and foreign software products shows that the use of digital technologies is one of the important factors that ensure the growth of productivity, resource saving, stability of production of agricultural products and raw materials, reduction of product losses. Developed modules of geoinformation application in combination with IT solutions for processing large arrays of data refers to the actual direction of digitalization of the agricultural sector and is of great practical value for improving the efficiency of agriculture and crop production. Application of such technologies will allow to provide effective and environmentally friendly work, preserve natural fertility of agricultural lands and effectively solve urgent environmental problems directly related to the conduct of rational agriculture.

Acknowledgments

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