# Intelligent photomonitoring of agricultural, forest and water lands. Results of research work of 2023

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# Intelligent photomonitoring of agricultural, forest and water lands

## Tasks

- Using NDVI dynamics for forecasting of crop yields
- Routing of agricultural UAV
- Filtering the overgrowth fields

# Using NDVI dynamics for forecasting of crop yields

# Introduction: on Crop Yields

## Review


- Ahmad, R., Yang, B., Ettlin, G., Berger, A., Rodriguez-Bocca, P. A machine learning based ConvLSTM architecture for NDVI forecasting (2020) https://doi.org/10.1111/itor.12887.
- Gao, P., Du, W., Lei, Q., Li, J., Zhang, Sh., Li, N. NDVI Forecasting Model Based on the Combination of Time Series Decomposition and CNN-LSTM (2023) https://doi.org/10.1007/s11269-022-03419-3.
- Ahmad, R., Yang, B., Rodriguez-Bocca, P. Deep Spatial-Temporal Graph Modeling for Effcient NDVI Forecasting (2023) https://doi.org/10.1016/j.atech.2023.100172.
- Huang, Sh., Ming, Bo, Huang, Q., Leng, G., Hou, B. A Case Study on a Combination NDVI Forecasting Model Based on the Entropy Weight Method (2017). https://doi.org/10.1007/s11269-017-1692-8.
- Fernandez-manso, A., Quintano, C., Fernandez-Manso, O. Forecast of NDVI in coniferous areas using temporal ARIMA analysis and climatic data at a regional scale (2011) https://doi.org/10.1080/01431160903586765.
- Alhamad, M., Stuth, J., Vannucci, M. Biophysical modelling and NDVI time series to project near-term forage supply (2007) https://doi.org/10.1080/01431160600954670.

# Introduction: on Crop Yields

## Review. Russian publications

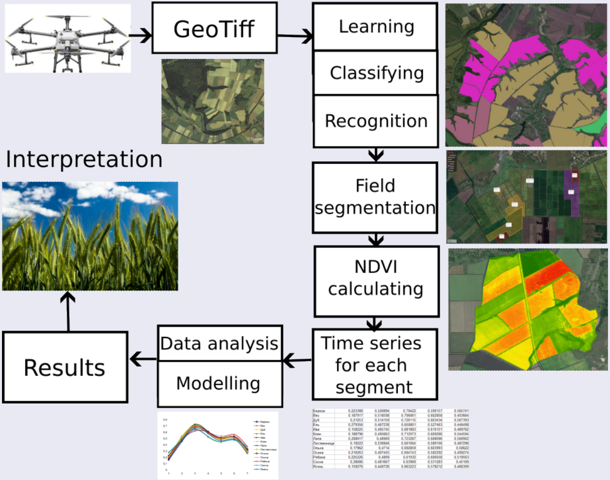

- Bukhovets, A. G., Semin, E.A., Kostenko, E.I., Yablonovskaya, S.I. Modelling of the dynamics of the NDVI vegetation index of winter wheat under the conditions of the CFD (2018) https://doi.org/10.17238/issn2071-2243.2018.2.186 (in Russian).
- Greben, A.S., Krasovskaya, I.G. Analysis of the main methods for forecasting yields using space monitoring data, in relation to grain crops in the steppe zone of Ukraine. Radio electronic and computer systems. 2 (54). 170–180 (2012). (in Russian).
- Spivak, L.F., Vitkovskaya, I.S., Batyrbayeva, M.Zh., Kauazov, A.M. Analysis of the results of forecasting the yield of spring wheat based on time series of statistical data and integral indices of vegetation. Modern problems of remote sensing of the Earth from space. 12 (2). 173–182 (2015).(in Russian).

# Monitoring of crop yields

- a higher level of detail, which is of particular interest to potential customers
- detecting the problematic areas of the field
- methods for identifying the parameters of a single quasilinear difference equation
- allows to get the model coefficients for any considered objects

# Data organizing

## The scheme of the analysis system executing



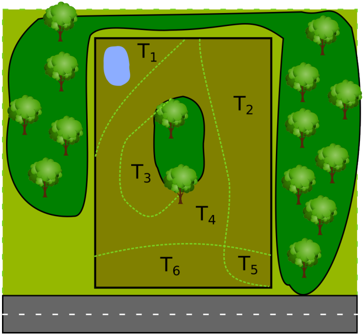
# Normalized Difference Vegetation Index (NDVI)

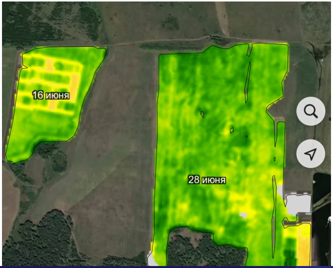
$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Properties:

- $NDVI \in [-1; 1]$
- $NDVI \leq 0$: buildings, structures, paved road surfaces, water surfaces, mountains, clouds and snow.
- $NDVI \in [0.1; 0.2)$: an open soil
- $NDVI \in [0.2; 0.4)$: the weak, sparse vegetation,
- $NDVI \in [0.4; 0.6)$: moderate vegetation,
- $NDVI \geq 0.6$: healthy, dense vegetation.

# Field Clustering

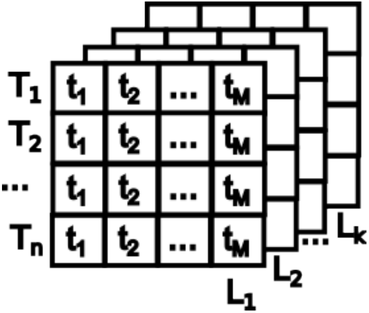



- $T_1$ corresponds the area near the pond, it's most likely low;
- $T_2$ and $T_3$ satisfy the shadowed area;
- $T_4$ is the common field without any peculiarities;
- $T_5$ is the shadowed area near the road;
- $T_6$ is the area near the road.

# Data Organizing

The matrix of values for each tile in time




- Monitoring of crops developing is made in 3–5 days
- the number of images $M$ is less than 50 per season
- the number of tiles $N$ depends on:
  - the real size of the recognized objects
  - properties of each object
- to describe the dynamic process for each tile of the recognized object we need to obtain the coefficients for $N$ models
- the task is solvable for each agricultural object separately

# General least deviations method estimation

## Statement of the problem

To determine the coefficients $a_1, a_2, a_3 \ldots, a_m \in \mathbb{R}$ of a $m$-th order quasilinear autoregressive model

$$y_t = \sum_{j=1}^{n(m)} a_j g_j(\{y_{t-k}\}_{k=1}^{m}) + \varepsilon_t, \quad t = 1, 2, \ldots, T$$

by up-to-date information about of values of state variables $\{y_t \in \mathbb{R}\}_{t=1-m}^{T}$ at time instants $t$; here $g_j : (\{y_{t-k}\}_{k=1}^{m}) \to \mathbb{R}$, j=1,2,...n(m) are given $n(m)$ functions, and $\{\varepsilon_t \in \mathbb{R}\}_{t=1}^{T}$ are unknown errors.

# General least deviations method

## Approach

Input: time series $\{y_t \in \mathbb{R}\}_{t=-1-m}^{T}$ of length $T + m \geq \left(1 + 3m + m^2\right)$
Output: factors $a_1, a_2, a_3 \ldots, a_m \in \mathbb{R}$
Optimization task

$$\sum_{t=1}^{T} \arctan \left| \sum_{j=1}^{n(m)} a_j g_j(\{y_{t-k}\}_{k=1}^{m}) - y_t \right| \to \min_{\{a_j\}_{j-1}^{n(m)} \subset \mathbb{R}}$$

The Cauchy distribution

$$F(\xi) = \frac{1}{\pi} \arctan(\xi) + \frac{1}{2}$$

has the maximum entropy among distributions of random variables that have no mathematical expectation and variance.

# General least deviations method

## The basic set $g_j(*)$

$$g_{(k)}(\{y_{t-k}\}_{k=1}^{m}) = y_{t-k},$$

$$g_{(kl)}(\{y_{t-k}\}_{k=1}^{m}) = y_{t-k} \cdot y_{t-l},$$

$$k = 1, 2, \ldots, m; \; l = k, k+1, \ldots, m.$$

- $n(m) = 2m + \mathrm{C}_m^2 = m(m+3)/2$
- the numbering of $g_{(*)}$ functions can be arbitrary

For $m = 2$ we have the following functions $g_{(*)}$:

$$g_1 = y_1, \quad g_2 = y_2, \quad g_3 = y_1^2, \quad g_4 = y_2^2, \quad g_5 = y_1 \cdot y_2.$$

# GLDM estimation task

- concave optimization problem
- entering the additional variables reduces it to LP task

$$\sum_{t=1}^{T} p_t z_t \to \min_{\substack{(a_1,a_2,\ldots,a_{n(m)})\in \mathrm{R}^m, \\ (z_1,z_2,\ldots,z_T)\in \mathrm{R}^T}}$$

$$-z_t \le \sum_{j=1}^{n(m)} [a_j g_j(\{y_{t-k}\}_{k=1}^{m})] - y_t \le z_t, \quad t = 1,2,\ldots,T,$$

$$z_t \ge 0, \quad t = 1,2,\ldots,T.$$

This task has a canonical type with variables $n(m) + T$ and $3n$ inequality constraints including the conditions of non-negativity of $z_j$, $j = 1,2,\ldots,T$.

# The dual task

$$\sum_{t=1}^{T} (u_t - v_t)\, y_t \to \max_{u,v \in \mathbb{R}^T},$$

$$\sum_{t=1}^{T} a_j g_j(\{y_{t-k}\}_{k=1}^{m})\,(u_t - v_t) = 0,\ j = 1, 2, \ldots, n(m),$$

$$u_t + v_t = p_t, \quad u_t,\, v_t \geq 0, \quad t = 1, 2, \ldots, T.$$

$$w_t = u_t - v_t,\ t = 1, 2, \ldots, T.$$

$$u_t = \frac{p_t + w_t}{2}, \quad v_t = \frac{p_t - w_t}{2}, \quad -p_t \leq w_t \leq p_t, \quad t = 1, 2, \ldots, T.$$

So the optimal solution of primal task is equal to the optimal solution of:

$$\sum_{t=1}^{T} w_t \cdot y_t \to \max_{w \in \mathbb{R}^T},$$

$$(1): \quad \sum_{t=1}^{T} g_j(\{y_{t-k}\}_{k=1}^{m}) \cdot w_t = 0,\ j = 1, 2, \ldots, n(m),$$

$$(2): \quad -p_t \leq w_t \leq p_t,\ t = 1, 2, \ldots, T.$$

# Constraints

Constraints (1) define $(T - n(m))$-dimensional linear variety $\mathcal{L}$ with $(n(m) \times T)$-matrix

$$S = \begin{bmatrix} g_1(\{y_{1-k}\}_{k=1}^m) & g_1(\{y_{2-k}\}_{k=1}^m) & \cdots & g_1(\{y_{T+1-k}\}_{k=1}^m) \\ g_2(\{y_{1-k}\}_{k=1}^m) & g_2(\{y_{2-k}\}_{k=1}^m) & \cdots & g_2(\{y_{T+1-k}\}_{k=1}^m) \\ \vdots & \vdots & \ddots & \vdots \\ g_{n(m)}(\{y_{1-k}\}_{k=1}^m) & g_{n(m)}(\{y_{1-k}\}_{k=1}^m) & \cdots & g_{n(m)}(\{y_{1-k}\}_{k=1}^m) \end{bmatrix}$$

Constraints (2) define $T$-dimensional parallelepiped $\mathcal{T}$.

# Solution

We obtain the solution by algorithm using the gradient projection of the objective function

$$\nabla = \{y_t\}_{t=1}^{T}$$

on the allowed area $\mathcal{L} \cap \mathcal{T}$ defined by the constraints (1)–(2).
The projection matrix:

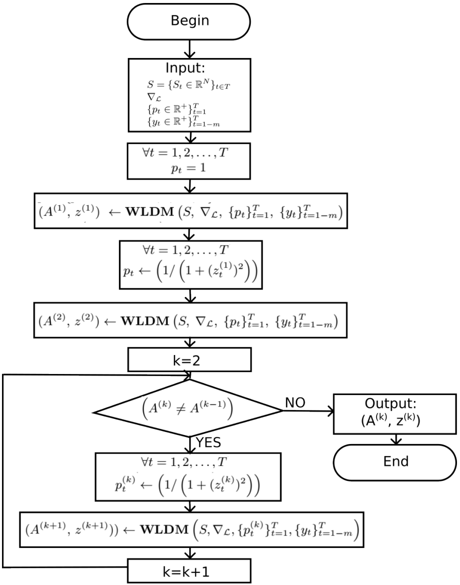
$$S_{\mathcal{L}} = E - S^T \cdot \left(S \cdot S^T\right)^{-1} \cdot S,$$

and gradient projection on $\mathcal{L}$ is:

$$\nabla_{\mathcal{L}} = S_{\mathcal{L}} \cdot \nabla$$

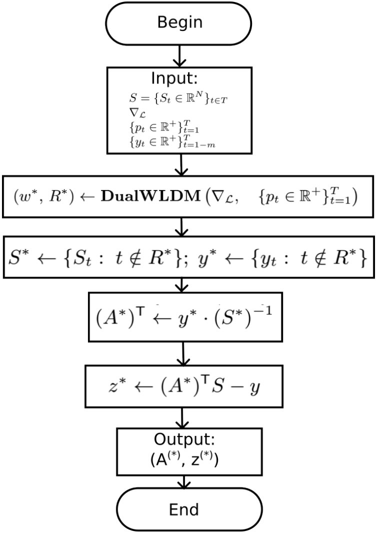
If outer normal on any parallelepiped face forms the sharp corner with gradient projection $\nabla_{\mathcal{L}}$ then movement by this face is equal to zero.

# The scheme of GLDM estimation algorithm




- Algorithm runs as the iteration process for obtaining optimal GLDM solution $A \in \mathbb{R}^{n(m)}$ and the vector of residuals $z \in \mathbb{R}^T$. This process stops when $\left(A^{(k)} = A^{(k-1)}\right)$.
- To obtain $A$ and $z$ we run the WLDM estimation algorithm

# WLDM estimation algorithm




- calculates the factors

$$a_1, a_2, a_3 \ldots, a_{n(m)} \in \mathbb{R}$$

by solving the optimization task

$$\sum_{t=1}^{T} p_t \cdot \left| \sum_{j=1}^{n(m)} a_j g_j(\{y_{t-k}\}_{k=1}^m) - y_t \right|$$

$$\rightarrow \min_{\{a_j\}_{j=1}^{n(m)} \in \mathbb{R}^{n(m)}}$$

# Solution

**Theorem 1**

Let

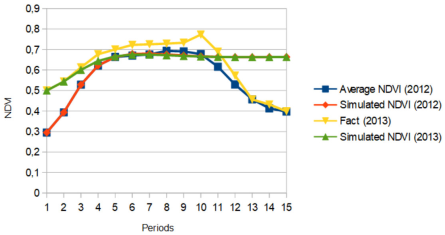
- $w^*$ be the optimal solution of the dual task,
- $(\{a_j^*\}_{j-1}^{n(m)}, z^*)$ be solution of a system of linear algebraic equations.

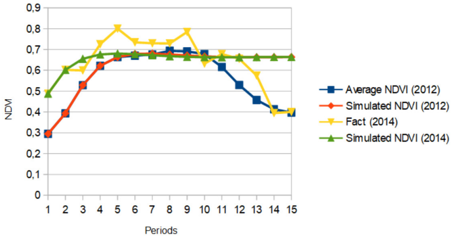
Then $\{a_j^*\}_{j-1}^{n(m)}$ is the optimal solution to the task WLDM.

**Theorem 2**

The sequence$\{\left(A^{(k)}, z^{(k)}\right)\}_{k=1}^{\infty}$, constructed by GLDM-estimator Algorithm, converges to the global minimum $(a^*, z^*)$ of the task GLDM.

# The dynamics of index for winter wheat sowing in Stavropol region




$$y_t = (3.46935 \cdot y_{t-1} - 2.18641 \cdot y_{t-2}) -$$

$$-5.59237 \cdot y_{t-1}^2 - 2.5635 \cdot y_{t-1} y_{t-2} +$$

$$+7.72991 \cdot y_{t-2}^2$$

Significance levels:

- 2012: 0,9445357262
- 2013: 0,7603522142
- 2014: 0,6913386433

# Conclusion

- The model can be used to approximate the missing values of the NDVI, estimate the time to reach the maximum value of the index and, therefore, predict the start of harvesting dates.
- its errors are not worse than ones for neural network approaches or classical statistical models but needs less computational resources
- a significant advantage in comparison with these models that is the opportunity to interpret the model coefficients in terms of the research problem

Further research:

- improving the algorithm for time series using arbitrary time periods
- application of the developed approach for multidimensional time series
- the research of different outer factors such as humidity and temperature influence

# Using NDVI dynamics for forecasting of crop yields

# Introduction: on Drone and Truck Task

## Review


- Makarovskikh, T.; Panyukov, A. Special Type Routing Problems in Plane Graphs. Mathematics 2022, 10, 795. doi: 10.3390/math10050795
- Petunin, A.A.; Polishchuk, E.G.; Ukolov, S.S. On the new Algorithm for Solving Continuous Cutting Problem. IFAC-PapersOnLine 2020, 52, Pp. 2320–2325.
- Petunin, A.A.; Chentsov, A.G.; Chentsov, P.A. Optimal routing in problems of sequential bypass of megacities in the presence of restrictions. Chelyab. Phys.-Math. journal, 2022, 7:2, Pp. 209–233.
- Chung, S.H., Sah, B., Lee, J. Optimization for drone and drone-truck combined operations: A review of the state of the art and future directions. Computers & Operations Research, 2020, 123, ID 105004, doi: 10.1016/j.cor.2020.105004.
- Castro, G.G.R.d. et al. Adaptive Path Planning for Fusing Rapidly Exploring Random Trees and Deep Reinforcement Learning in an Agriculture Dynamic UAVs. Agriculture 2023, 13, 354. doi: 10.3390/agriculture13020354
- Tian H. et al. (2023) Design and validation of a multi-objective waypoint planning algorithm for UAV spraying in orchards based on improved ant colony algorithm. Front. Plant Sci. 14:1101828. doi: 10.3389/fpls.2023.1101828
- Lobaty A.A., Bumai A.Y., Avsievich A.M. Formation of unmanned aircraft trajectory when flying around prohibited areas. System analysis and applied information science. 2021, 4, Pp. 47–53. (In Russ.) https://doi.org/10.21122/2309-4923-2021-4-47-53
- Rudenko E.M., Semikina E.V. Intelligent monitoring of UAV group on eyler-hamilton reference graphs on the local. Institute of Engineering Physics. 2021. Vol. 62. No. 4. Pp.

# Statement of the Problem and Constraints (1)

- a farm that owns $N$ fields,
- each field is inscribed in a rectangle $F_i = \{l_i \times w_i\}$, $i = \overline{1, N}$,
- the coordinates of the upper left corner of each such rectangle are saved in WGS84[a]
- dimensions of the rectangle are $l_i$ and $w_i$, $i = \overline{1, N}$.

[a] World Geodetic Parameters of the Earth 1984, which includes the system of geocentric coordinates. Unlike local systems, it is a single system for the entire planet.

# Constraints

- $C_{call}$: one rising of a drone cost
  - the working time of an operator and one battery charge,
  - the number of charges for one battery is limited,
  - the cost of a new battery is proportionally divided between all its charges
- $C_{way}$: the cost of transfer the brigade truck to the place of shooting;
- characteristics of the selected drone for research:
  - $T_{av}$: average flight time before recharging,
  - average velocities of ascent to a given height $V_{up}$ and flight $V_{flight}$;
- $S_a$: the size of an area taken from above;
- $a_x$, $a_y$: camera aspect ratio;
- $h$: the height of monitoring;
- $C_{recharge}$: drone restart cost;
- $P \in [0; 1)$: image overlay percentage;
- drone returns for recharging to the truck that is placed in a starting point or moves to any allowed point at the boundary of a field, and continues monitoring after recharging.

# Task

- to search a drone flight path for the given map of areas that satisfies the imposed constraints and parameters,
- determine the optimal starting point,
- minimize the number of drone recharges and minimize the distances between the launch points of the device

# Stages

- Let flight time is not limited and explored area is connected
- Let the flight time is not limited but explored area is not connected.
- Let the flight time is limited by the drone battery capacity, but the location of start is any point. The field is not connected.
- The general case when the flight time is limited by battery capacity, and location of possible starting points is fixed due to some restrictions
- The general case as the previous one, but the investigated area has any shape, not only rectangle.
- To take into account the influence the external factors to improve the drone flight trajectory.

# Known Models

[Chung2020]:

- several mathematical models and problems based on the concept of DTCO (TSPD+VRPD)
- the delivery task when the aim is to determine the order of drone flyby or the territory surved (FSTSP, PDSTSP [Murray2015], PDSTSP+DP [Ham2018], TSP-D [Agatz2018] etc.)

[Chung2020] Chung, S.H., Sah, B., Lee, J. Optimization for drone and drone-truck combined operations: A review of the state of the art and future directions. Computers & Operations Research, 2020, 123, ID 105004, doi: 10.1016/j.cor.2020.105004.
[Murray2015] Murray, C.C., Chu, A.G., 2015. The flying sidekick traveling salesman problem: optimization of drone-assisted parcel delivery. Transp. Res. C Emerg. Technol. 54, 86вЂ“109.
[Ham2018] Ham, A.M. Integrated scheduling of m-truck, m-drone, and m-depot constrained by time-window, drop-pickup, and m-visit using constraint programming, Transportation Research Part C. Emerging Technologies, 2018, 91, Pp. 1–14, doi: 10.1016/j.trc.2018.03.025.
[Agatz2018] Agatz, N., Bouman, P., Schmidt, M., 2018. Optimization approaches for the traveling salesman problem with drone. Transp. Sci. 52 (4), Pp. 965–981.

# Considered Task

- we discuss the drone trajectory used for monitoring of crop yields, i.e. the minimal sequence of rectangles covering the investigated area
- we need one drone and one truck
- the nodes are divided into three categories:
  - drone node: a node visited by a drone only,
  - truck node: a node visited by a truck only,
  - combined node: a node visited by a truck and a drone.
- Approaches: [Agatz2018], [Makarovskikh2022]
- Solution: the combination of a truck route (composed of the truck and combined nodes) and a drone route (composed of the drone and combined nodes)
- the considered case of yields monitoring is to be a particular case allowing solving our task by polynomial time

[Agatz2018] Agatz, N., Bouman, P., Schmidt, M., 2018. Optimization approaches for the traveling salesman problem with drone. Transp. Sci. 52 (4), Pp. 965–981.
[Makarovskikh2022] Makarovskikh, T.; Panyukov, A. Special Type Routing Problems in Plane Graphs. Mathematics 2022, 10, 795. doi: 10.3390/math10050795

# Graph Model

- Plane graph $G_{F_i} = (V_{F_i}, E_{F_i})$ for each investigated area (field) $F_i$,
- the set of vertices $V_{F_i}$ of which be the points of shooting by the drone camera,
- $E_{F_i}$ be the connections between the nearest neighbours.

Each $S_a = (a_x \cdot K) \cdot (a_y \cdot K) = K^2 \cdot a_x a_y$, then lengths of each photo size are equal to

$$X = a_x \cdot K = a_x \cdot \sqrt{\frac{S_a}{a_x a_y}}, \quad Y = a_y \cdot K = a_y \cdot \sqrt{\frac{S_a}{a_x a_y}}.$$

The point of shooting be the center of the picture.
The point of the next shooting for current shot $(x_{cur}, y_{cur})$ with overlay $P$:

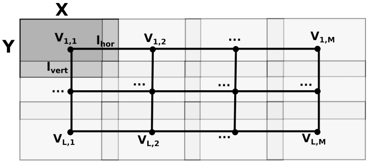
$$x_{next} = x_{cur} + X - X \cdot P, \quad y_{next} = y_{cur}$$

for moving along the rectangle width or

$$x_{next} = x_{cur}, \quad y_{next} = y_{cur} + Y - Y \cdot P$$

for moving along the rectangle height.

# Graph Model (2)




- The optimal path $P(F_i)$ for the rectangular area $F_i$
- we need moving only horizontally or vertically,
- Vertices: $v_{ij} \in V_{F_i}$, $i = \overline{1, M}$, $j = \overline{1, L}$, $|V_{F_i}| = M \cdot L$,
- Edges $e \in E_{F_i}$ correspond to possible moves from each vertex, $|E_{F_i}| = (M - 1) \cdot (L - 1)$.

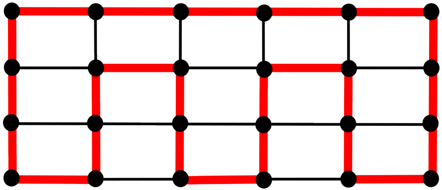
## Features

- One half of edges $e \in E_{F_i}$ has length $l_{vert} = Y - Y \cdot P$
- another one has length $l_{hor} = X - X \cdot P$.
- Task: to define the Hamiltonian cycle of the shortest length in this graph.
- Since $a_x \neq a_y$, without loss of generality, let's consider that $a_x > a_y$, and $l_{vert} < l_{hor}$ .
- half of edges is shorter then the others, then to get the shortest path we need:
  - include as much as possible these short edges of length $l_{vert}$;
  - as less as possible of long edges of length $l_{hor}$.
- in any case the minimal number of long edges in a route is equal to $2 \cdot (M - 1)$.

# Cases for the shortest path of flyby a single $F_i$

Case 1: $M$ is even for any $L$. The length of the route is equal to

$$R = 2(M-1)l_{hor} + (2(L-1) + (M-2)(L-2))l_{vert};$$



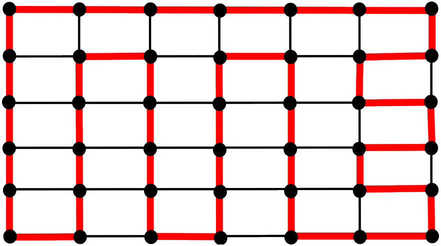
Case 2: $M$ is odd, $L$ is even. The length of the route is equal to:

a Avoiding idle passes:

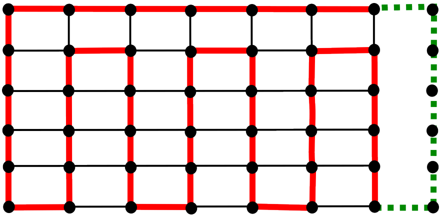
$$R = (2(M-1) + (L-2))l_{hor} + (2(L-1) + (M-2)(L-2))l_{vert}$$

b Allowing idle passes:

$$R = 2(M-1)l_{hor} + ((L-1) + (M-1)(L-2))l_{vert} + L_{idle},$$
$$L_{idle} = 2l_{hor} + (L-1)l_{vert}$$



(a)



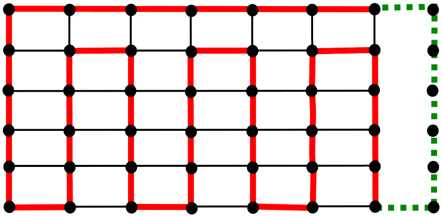
(b)

# Cases for the shortest path of flyby a single $F_i$

Case 3: both $M$ and $L$ are even. The length of the route is calculated the same way as for the previous case with idle pass.

$$R = 2(M-1)l_{hor} + ((L-1) + (M-1)(L-2))l_{vert} + L_{idle},$$

$$L_{idle} = 2l_{hor} + (L-1)l_{vert}$$



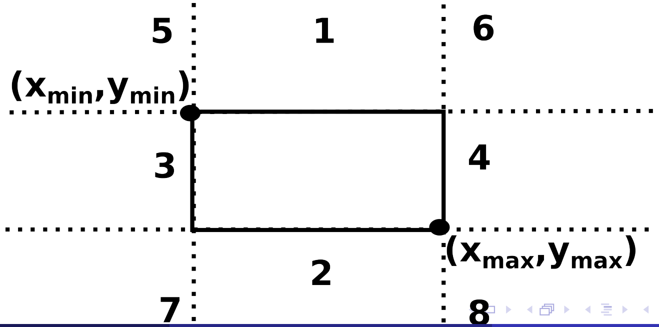
# Algorithm for Shortest Connecting of Areas

- Let the farmer needs monitoring of more than one field.
- If the boundaries of the fields are combined or are at a distance of several tens of meters these fields can be united to one investigated area.
- In common fields may lie in distance of several kilometres from each other.
- The approach used for connecting the different areas under research may be similar to [Petunin2022].

[Petunin2022] Petunin, A.A.; Chentsov, A.G.; Chentsov, P.A. Optimal routing in problems of sequential bypass of megacities in the presence of restrictions. Chelyab. Phys.-Math. journal, 2022, 7:2, Pp. 209–233.

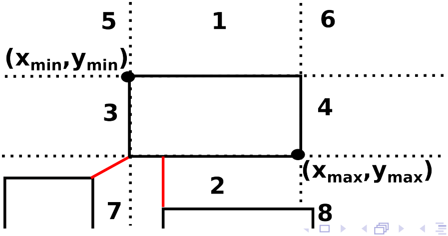
# Peculiarities of the applied task

Constraint: if the distance between boundaries of two fields takes time less than drone landing and takeoff time then these fields are connected to one object.
Task: Define the shortest distance between boundaries of fields $F_i$. We use only vertices of graph $G$ belonging to outer face.
All fields $F_i$ are considered to be rectangles. Consider the rectangle $F_i = \{(x^i_{min}, y^i_{min}), (x^i_{max}, y^i_{max})\}$. All the outer space of this rectangle is divided into 8 areas.

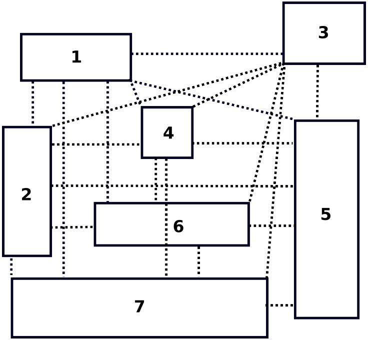


# The nearest rectangles (List of Rules)

1. If the straight line $l$ passing along the boundary of rectangle $F_i$, $i = \overline{1, N}$ intersects the boundary of rectangle $F_j$, $j \neq i$, $j = \overline{1, N}$ then the segment of $l$ between $F_i$ and $F_j$ be the shortest way between them.
2. For each pair of rectangles $F_i$ and $F_j$, $j \neq i$, $i, j = \overline{1, N}$ there exists the segment connecting them.
3. If there are 2 segments $A$ and $B$ between rectangles $F_i$ and $F_j$, $j \neq i$, $i, j = \overline{1, N}$, and their lengths $L(A) = L(B)$ then for any segment $C$ between $A$ and $B$ the equality $L(A) = L(B) = L(C)$ holds.
4. If $F_j$ belongs to areas 5–8 of rectangle $F_i$ outer space, $j \neq i$, $i, j = \overline{1, N}$, then the shortest segment connects one of the following pairs of points:
   - $(x^i_{min}, y^i_{min})$ and $(x^j_{max}, y^j_{max})$ (area 5 of $F_i$) or $(x^j_{min}, y^j_{min})$ and $(x^i_{max}, y^i_{max})$ (area 8 of $F_i$);
   - $(x^i_{min}, y^i_{max})$ and $(x^j_{max}, y^j_{min})$ (area 6 of $F_i$) or $(x^j_{max}, y^j_{min})$ and $(x^i_{min}, y^i_{max})$ (area 7 of $F_i$).

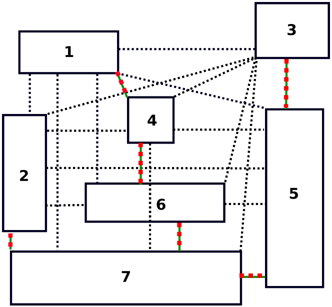


# The shortest connections between rectangles belonging to different areas




- Using these rules we can calculate the shortest connections between all pairs of rectangles $F_i$, $i = \overline{1, N}$.
- If $F_i$ be the vertices of the connections graph $G_c$:
  - its edges $e \in E(G_c)$ be the connections,
  - weight $w(e)$ of each $e \in E(G_c)$ be the length of the segment.
- $G_c = K_{|F_i|}$.

# The minimal spanning tree for the given flight plan



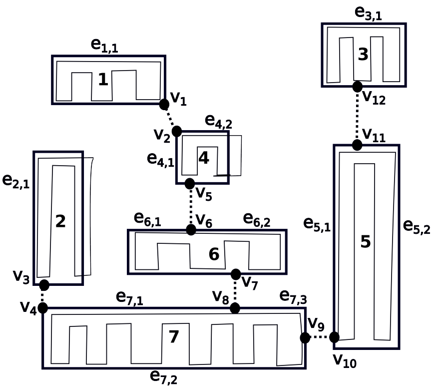

- To get the shortest connection between $F_i$ we need define the minimal spanning tree $T(G_c)$

**Theorem 1**

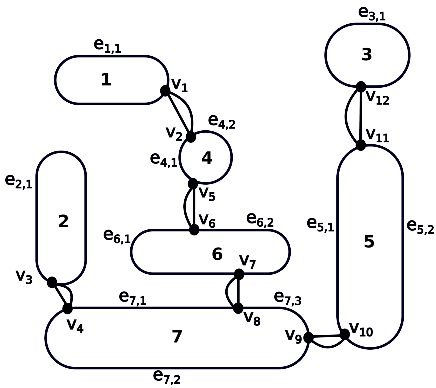
The obtaining the minimal length connections between all $F_i$, $i = \overline{1, N}$ can be run in polynomial time.

# Flyby graph

We have connected graph $G_p = (V_p, E_p)$, $E_p = E(P(F_i)) \cup E(T(G_c))$ corresponding to a drone path.




(a)



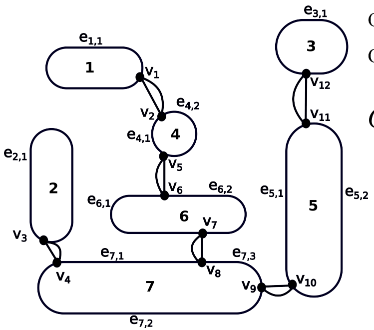

(b)

# Flyby Graph (Explanation)

a in common the degree of $v_i \in V_p$ may be either odd or even. So, to fly by the defined path with the defined connections and return to initial point (drone returns to truck) we need pass edges $E(T(G_c))$ connecting the odd vertices twice or define the shortest matching between them.

b the odd vertices are connected twice, we have connected 4-regular graph with cut vertices

# AOE-chain for plane connected 4-regular graph




one of the possible solutions of the considered graph:

$$C(G_p) = v_1 e_{1,1} v_2 e_{4,1} v_5 v_6 e_{6,1} v_7 v_8 e_{7,1} v_4 v_3 \\ e_{2,1} v_3 v_4 e_{7,2} v_9 v_{10} e_{5,2} v_{11} v_{12} e_{3,1} \\ v_{12} v_{11} e_{5,1} v_{10} v_9 e_{7,3} v_8 v_7 e_{6,2} v_6 v_5 \\ e_{4,2} v_2 v_1.$$

# Drone path for the limited time of flight

1. drone node: a node visited by a drone only, they are the points of a field $F_i$ not belonging boundary or nodes marked as unreachable by truck;
2. combined node: a node visited both by a truck and a drone (for both monitoring and recharging), it is a node belonging boundary of the field reachable by truck.

# Rules of Recharging

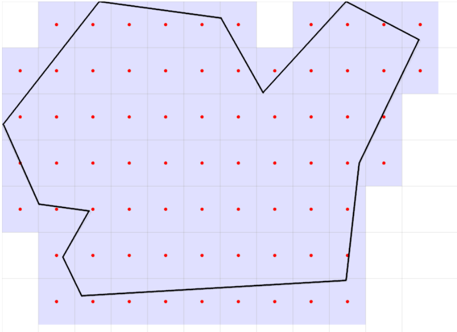
1. $G_p = (V_p, E_p)$, $V_p = V_{drone} \cup V_{truck}$, $V_{comb} = V_{drone} \cap V_{truck}$.
2. Recharging points: $T_{flight} = T_{up} + T_{explore} + T_{down}$, where
   - $T_{up}$ be the time for rising the drone,
   - $T_{down}$ be the time for drone descent,
   - $T_{explore}$ be the time for shooting.
3. Ideal case: $S_{flight} = V_{flight} \cdot T_{explore}$ be the maximal length of drone path.
4. For safe drone descent we need pass the way shorter than $S_{flight}$
   - drone goes down in the nearest combined node $v^* \in V_{comb}$ before length $S_{flight}$ is reached
   - we put the truck to node $v^*$.
   - Knowing the way for a drone $C(G_p)$ we can define the nodes $v_1^*, v_2^*, \ldots v_k^*$ where the truck waits for drone for recharging.

# Drone Optimal Path with Recharges

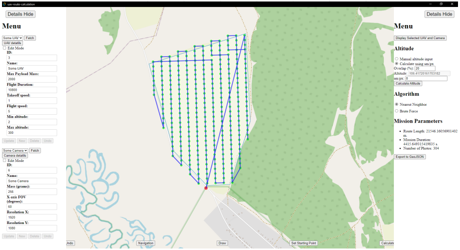
- Use algorithm PPOE-Cover [Makarovskikh2022] where all the vertices of graph (nodes) are defined as:
  - $V_{in}$ (be the starting points of chains)
  - $V_{out}$ (be the ending nodes of chains)
- Algorithm PPOE-Cover defines the path in a graph with optimal length connections between odd vertices.

Open tasks: take outer factors into account

# Computational experiment



- Discretisation algorithm: the rectangles included in the survey area are highlighted in purple, the survey points are marked in red.




- Application for obtaining the drone flight path.

# Conclusion

- The considered type of drone and truck problem has lot of unsolved tasks concerning different technological constraints.
- Restrictions on flight time and height, on placement of truck, on properties of camera, and weather conditions are among them.
- We considered the problem of planning the drone path with several easy constraints: we run our drone and truck system in the ideal weather (no wind, positive temperature), and suppose that truck can parking in almost all outer border points.
- We defined the way of obtaining the drone flight trajectory for monitoring the objects of interest to the customer and determining the number and place for recharging. For this purpose we used the developed earlier polynomial routing algorithm.

# Filtering the overgrowth fields

## Statement of the problem

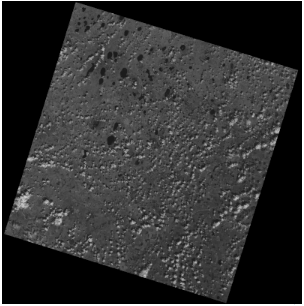
- Overgrowth of agricultural land is a significant economic problem.
- The lands belonging to the agricultural category must be used for their purpose.
- According to the law, they cannot stand idle for a long time and not be cultivated at all: in this case, they are seized from the owner.

### Problem

Since the 1990s, many unused agricultural lands have not been accounted. The fields located in the forest zone were again covered with woody vegetation which significantly complicates the identification of the former field and reduces the possibility of its further cultivation.

# Initial data

- Multispectral images (freely available images from the Landsat satellite)
- GeoTIFF format (a multi-layered bitmap consisting of millions of pixels)
- Each layer of image corresponds to one of the shooting channels
- The image is a seamless mosaic color-synthesizing image,
- in some cases some of the pixels of this image are blocked by clouds, which can lead to a number of analysis errors.



# Images characteristics

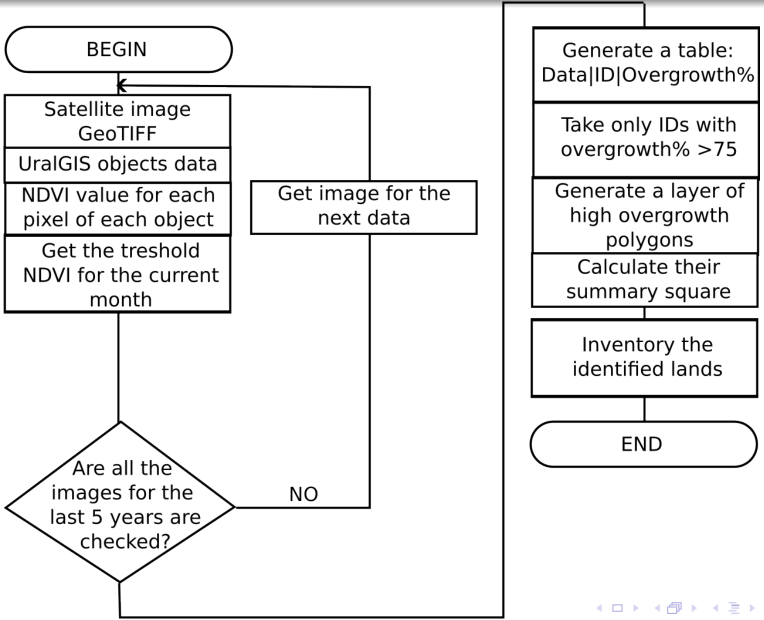
- The shooting date range is from May to September
- The frequency of shooting is 1 time in 5 days
- The range of angles of the Sun is 20–90 degrees
- The viewing angle is –40/40
- The acceptable percentage of clouds is 15

# Tools

- Programming language Python 3
- tools for working with geoinformation
  - libraries that provide the ability to obtain from a multispectral image a fragment corresponding to a polygon specified in binary format
  - Shupely: converts data from binary format into internal objects (polygons or lines) and uses them to crop images.

At the output, we have an image in a matrix representation for each polygon stored in the database.

# Algorithm


BEGIN
Satellite image GeoTIFF
UralGIS objects data
NDVI value for each pixel of each object
Get the treshold NDVI for the current month
Are all the images for the last 5 years are checked?
NO
Get image for the next data
Generate a table: Data|ID|Overgrowth%
Take only IDs with overgrowth% >75
Generate a layer of high overgrowth polygons
Calculate their summary square
Inventory the identified lands
END

# Threshold values

Treshold NDVI[1]

| May | June | July | August | September |
|---|---|---|---|---|
| 0,49 | 0,68 | 0,59 | 0,49 | 0,51 |

Treshold owergrowth: 0.75 [2]

[1] Munzer Nur.Development of a methodology for using satellite imagery data for forest monitoring : dissertation of Candidate of Technical Sciences : 25.00.34 / Munzer Nur; [Place of defense: Moscow State University of Geodesy and Cartography»]. - Moscow, 2021. - 150 p. : ill.

[2] Decree of the Government of the Russian Federation No. 1043 of June 8, 2022 «On Amendments to the Regulation on the Specifics of the Use, Protection, Protection, Reproduction of Forests Located on agricultural lands»

# Results

- The developed software integrated into the UralGIS-Agro system as a microservice
- Software runs by clicking "Create a layer for forest fund transfer"button
- The resulting sample is saved in a separate table for display as a separate layer
- Further actions and decision-making are carried out by experts in the relevant field.