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Articles

Monitoring the Condition of Hydraulic Structures during the Inter-Flood Period

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Abstract

The article is devoted to the issues of operational monitoring of the state of the infrastructure of hydraulic structures in the inter-flood period after the active impact of a powerful water flow during an ice break. For the design of repair and restoration works, a thorough examination of the condition of the riverbed and walls of hydraulic structures is necessary, on the basis of which a visual three-dimensional model is built. For visual observation, it is proposed to use a water drone equipped with pressure and temperature sensors, as well as a gyroscope-accelerometer and a magnetic compass. The main objective of the study is to plan the trajectory of a water drone in the reservoir area in order to build the most adequate model of its depths, the condition of the mooring walls and coastal slopes, with the recording of sensor readings in a database and operational visualization of the data obtained. To examine the condition of the walls of hydraulic structures, both visual and instrumental built-in monitoring tools are used to track the values of the main indicators of the condition of reinforced concrete structures. Monitoring of the groundwater level is a prerequisite for the adequate functioning of hydraulic structures. This is necessary for modeling the hydrological balance, which allows making informed decisions on water resources management and preventing negative consequences for the environment. It is also very important to monitor the depths of the fairway and the condition of the coastal slopes.

Keywords: riverbed fairway, hydraulic structures, condition monitoring, measurement filtering, measurement sensors, autonomous drones.

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1. Introduction

River valleys and floodplains are naturally designed to handle so-called "large water" flow. However, humans have always settled near riverbanks because rivers served as means of communication, water supply, energy, irrigation, and recreation. Many floodplains and low-lying areas are built up with houses and outbuildings despite the risk of flooding. One major downside of living near water is the potential for flooding during high water periods, especially in spring or during prolonged rains (Budin, 2008). Free river flow is regulated by hydraulic structures, and riverbeds are obstructed by dams and locks (Figure 1), which increases pollutant runoff due to higher flow velocity, reduced sedimentation, and natural floodplain purification. This also increases the risks of flooding, waterlogging, and inundation.

Fig. 1. Dam of a hydraulic structure

2. Objective of the Study

The main objective of the study is to develop a methodology for rapid automated monitoring of the condition of hydraulic structures and riverbeds after a flood to construct a visual 3D model for restoration work planning.

3. Discussion

Problem Statement

The primary task of the research is to build a model of the river fairway and hydraulic structure walls to create the most accurate representation of their condition, along with the state of quay walls and coastal slopes, recording sensor readings in a database and providing real-time visualization of the obtained data for planning repair and restoration work.

Solution Methods

The main research device proposed is the underwater drone "Oceanica Bathyscaphe" and a set of sensors embedded in hydraulic structures. The "Oceanica Bathyscaphe" is a smart robot capable of operating in both seawater and freshwater. The drone is fully controlled via a remote control unit included in the package. The operator can control the underwater movement speed of the robot, which supports three different speed modes. The drone's configuration includes an external navigation module equipped with sensors: a six-axis gyroscope-accelerometer, a three-axis magnetic compass, a pressure sensor, and a temperature sensor. The core of the Oceanica Bathyscaphe is the Raspberry Pi3 microcomputer (Figure 2; Jiang, 2025).

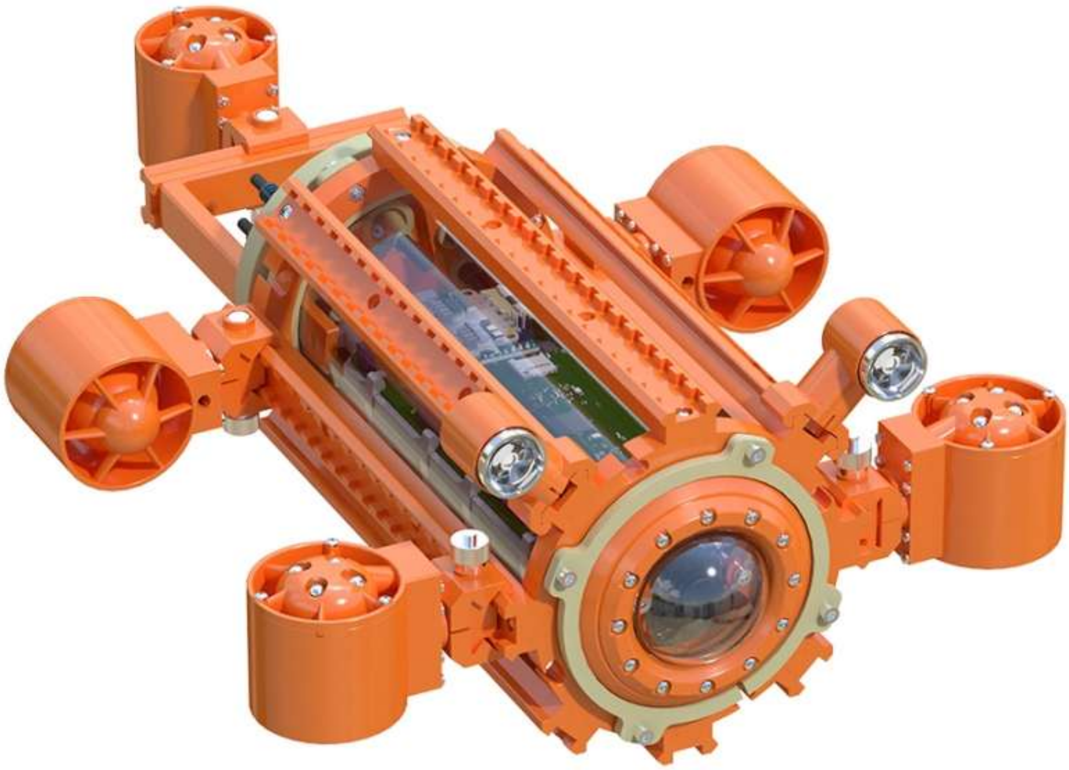

Fig. 2. Oceanica Bathyscaphe Robot

This robot is capable of:

– Diving to depths of up to 50 meters in both freshwater and saltwater;

– Recording video and taking photos underwater on a mobile device and saving them in memory;

– Capturing images with 8-megapixel resolution and recording Full HD video;

– Turning powerful lights on/off with adjustable brightness;

– Moving in six directions: up, down, forward, backward, right, and left;

– Transmitting system status data to a mobile device display;

– Collecting objects, lifting metal items, and monitoring water conditions;

– Moving underwater at three different speeds;

– Capturing photos and videos underwater while simultaneously viewing the captured images;

– Maintaining a connection with a mobile device at distances up to 30 meters.

Monitoring the Condition of Quay Walls

During the operation of quay structures, mechanical damage, metal corrosion, and concrete erosion are commonly encountered. The destruction of a pier begins from the moment the structure is commissioned. The slow degradation of construction materials occurs under the influence of the environment (Figure 3). Unlike mechanical damage, corrosion and erosion involve the dispersion and oxidation of the affected metal, often resulting in irreversible loss. Any construction material can be subject to corrosive or erosive damage.

In addition to these types of material degradation, others may also occur. For organic materials (wood), biological degradation caused by bacteria, fungi, or insects is often the main issue. For materials such as plastics, paints, and rubber, aging processes – gradual irreversible changes in internal structure and properties – are hazardous, often occurring in undesirable directions.

Fig. 3. Destruction of quay structures

All issues related to the operation of hydraulic structures, quay structures, and dams inevitably encounter the problem of ice impact.

The following types of ice impact on hydraulic structures (HST) are distinguished (Budin, 2008; Peschansky, 1967; Fomicheva, Kofeeva, 2022):

– Static pressure of a continuous ice cover during thermal expansion caused by air temperature changes;

– Impact of ice adhering to the structure during water level fluctuations;

– Static pressure of freely floating ice fields when pushed against the structure by wind and current;

– Dynamic pressure of freely floating ice fields and ice floes caused by ice drift, current, or wind;

– Dynamic impact of ice jams or blockages;

– Abrasive impact of ice floes on the structure surface during their movement influenced by wind, current, and water level fluctuations.

Additionally, for detecting metal corrosion and concrete erosion, visual inspection of quay walls using aerial and underwater drones is necessary.

Monitoring the Condition of Lock Walls.

The main feature of hydraulic structures (HST) is the need for continuous observation of their condition to prevent or timely address emergencies due to the influence of technogenic and natural hazards.

Safety monitoring of hydraulic structures is essential since these types of facilities are potentially dangerous, and any accident can result in catastrophic consequences. Therefore, implementing modern methodologies and equipment for control today is a necessity. Two types of HST condition observation are distinguished (Bolgov et al., 2013; Fomicheva, 2019; Panfilov, 1965; Korzhavin, 1973; Tsilikin, 1972):

– **Visual**: Involves visual inspection and the use of simple measuring instruments. These allow identifying defects, such as cracks that appear after natural disasters.

– **Instrumental**: Includes the use of control and measurement equipment, enabling continuous or short-interval monitoring.

Modern safety monitoring of HST primarily relies on automatic systems incorporating a complex of sensors, software, and equipment necessary for decoding signals from sensors and displaying them on the dispatcher's monitor. Such equipment allows continuous tracking of the technical condition of HST and automatically alerts the dispatcher and personnel of any malfunctions, enabling timely repairs or evacuation. As we can see, automatic HST monitoring ensures the safety of both the facility and the working personnel.

An automated monitoring system should track:

– Stress-strain state (SSS) of concrete structures;

– Piezometric head and filtration flow rate;

– Horizontal plane displacement of the structure or its elements;

– Structural settlement;

– Deviations from the normal angle.

For continuous monitoring of the technical condition of HST, a wide range of various sensors is employed. Most accurately, information is displayed from sensors installed in hydraulic structures during the construction stage. Among such equipment, the following can be highlighted:

– Piezometers on hydraulic structures ensure control of filtration head.

– Inclinometers measure the degree of horizontal soil deformation and structural settlement.

– Crackmeters determine the displacement of parts of the structure relative to each other.

– Strain gauges monitor the SSS of concrete structural elements.

Complex hydraulic structures (HST), such as hydroelectric power plants, dams, embankments, and marine port infrastructure objects (docks, locks, piers, etc.), are among the most dangerous objects in terms of potential accident consequences. To predict, prevent accidents timely, and assess HST safety, continuous monitoring of the technical condition of these hydraulic structures is required. Piezometry is widely used in automated industrial safety control systems for HST as a basic methodology for production measurement of hydrostatic or hydrodynamic pressure of liquids and solid deformations. Using various types of piezometers within the structure of automated geotechnical monitoring systems for HST, the following critical control tasks are addressed:

– Filtration pressure on the foundations of concrete hydraulic structures (dams, embankments), filtration deformations of the structure and foundations;

– Piezometric heads and hydraulic regime of HST, their foundations, and shore joints;

– Stresses in construction materials, at monitoring points in various zones inside the structures (including pore pressure);

– Level and temperature parameters of groundwater, allowing assessment of changes in the density and permeability of HST soils during long-term operation and the impact of these processes on the reliability of their foundations;

– Vertical and horizontal displacements of HST, settlements, mutual displacements of their elements and foundations;

– Zones, magnitudes, and sizes of structure deformations, length, and crack opening.

Classification, Device, and Principles of Piezometer Installation.

1) By installation method:

– Embedded – installed during the construction of the hydraulic structure;

– Drop-in – used in constructing and constructed HST.

2) By location of the measuring instrument's water intake:

– Surface;

– Deep;

– Point;

3) By location of the sensor mouth:

– Non-pressure;

– Pressure.

Principle of Operation of a String Piezometer.

The principle of operation depends on the frequency of string oscillations according to their tension degree. When water pressure changes in the structure where the sensor is installed, the tension of the string, which is the measuring element, changes. The oscillation frequency of the sensor string is proportional to the water pressure in the structure. One end of the string is fixed inside the sensor body, and the other is on a sensitive diaphragm. Piezometer data is transmitted to a reading device through a signal cable attached to the sensor.

Control of Filtration Heads.

Non-pressure piezometers, consisting of a pipe up to 35-40 m long, a filter located at the lower end of the pipe, and a head, control filtration heads. Piezometers are installed in pre-drilled piezometric wells in the structure. During piezometer installation in the piezometric well, a watertight "plug" is created above it (and if necessary, below it). The filter communicates with the surface through two hollow tubes where measurements are taken.

Water level (mm) in non-pressure piezometers is measured using a tape measure with a bell or whistle lowered into the well on a marked rope. The accuracy of the device is 1 cm at well depths up to 10 m and 2-3 cm at depths over 25 m.

The number and location of piezometers are determined in each specific project based on control tasks, design scheme, structure of the hydraulic structure, geological and hydrological features of the object, and other conditions.

For various designs of earthen dams, embankments, and typical engineering-geological foundation conditions, principal schemes of piezometric (observation) cross-section equipment are developed. On dams or embankments, piezometric cross-sections are located 100-150 m apart in the riverbed part and 150-250 m apart in the floodplain. At least three cross-sections are placed in the body of the HST and in the shore joints. Each cross-section must have at least three piezometers and a minimum of one in the downstream area of the hydraulic structures.

Application of Piezometers for Measuring Pore Pressure in Soil Mass.

Automatic piezometers with sensors of various types (electrical or vibrating string piezometer) are often used in geotechnical monitoring projects of HST. Sensors are installed in dispersive soils for automatic monitoring of pore pressure changes in hydraulic structures and groundwater levels (GWL) in the soil mass foundation of HST. Such devices can be equipped with filters of various pore diameters for solving complex measurement tasks. Automatic piezometers allow:

– Monitoring changes in hydrostatic pressure and gradient during HST operation;
– Evaluating the effectiveness of anti-filtration measures;
– Creating hydrogeodynamic models.

Piezometers can be used to observe changes in hydrogeological parameters (groundwater dynamics) in isolated aquifers.

Groundwater level is a key indicator of the state of underground water resources.

Monitoring Groundwater Levels

Monitoring groundwater levels is crucial for various sectors, including agriculture, construction, and ecology. High groundwater levels can lead to flooding and damage agricultural lands, as well as structures and building foundations. Conversely, low groundwater levels can cause drought and reduce the availability of drinking water.

Changes in groundwater levels can have serious environmental consequences. Rising groundwater levels can alter landscapes, reduce soil quality, and degrade ecosystems. On the other hand, declining groundwater levels can dry up rivers and lakes, negatively affecting animals and vegetation.

Various methods are used to monitor groundwater levels, including well monitoring, measuring underground water levels, and modeling the hydrological balance. This data helps make informed decisions about water resource management and preventing negative environmental impacts.

Well monitoring can utilize the Solinst Levelogger recorder and telemetry LevelSender 9500.

The Solinst Levelogger is a compact recorder that measures water level and temperature in a well. It is equipped with high-accuracy sensors and can record data to its internal memory.

The LevelSender 9500 is a telemetry system that transmits data from the Solinst Levelogger via email. Thus, obtaining monitoring data without physical presence at the well becomes possible (Figure 4).

Fig. 4. Solinst Levelogger Recorder

Monitoring groundwater levels is an integral part of managing underground water resources. Understanding the importance of this indicator and its consequences helps ensure sustainable use of underground water and environmental protection.

This sensor conveniently measures water levels at any time, as the device is lowered into a specially installed piezometric tube with a mounted submersible pump, rather than directly on its own cable into the water intake well. Piezometric measurements can be conducted manually or automatically.

The implementation of an automated monitoring system provides real-time comprehensive and reliable information about the state of the hydraulic object, thus minimizing the risks of accidents, emergencies, and eliminating material and human losses.

Monitoring the Condition of Coastal Slopes

The process of bank collapse is most pronounced in newly created reservoirs. The initial shape of the coastal zone often no longer corresponds to the project after exposure to water masses, primarily waves and currents. These discrepancies lead to intense deformations in the coastal zone and the creation of new bank forms, particularly the formation of a coastal shallows, altering both the above-water and underwater parts of the slopes.

Longshore currents, especially destructive during floods, play a significant role in bank formation. With good transport capacity due to high velocities and turbulence, currents move erosion products from erosion zones (headlands) to accumulation zones (bays and coves), where bars and spits form, narrowing the fairway and complicating ship approaches to piers.

Bank destruction by ice is due to its significant force both during ice movements and during the ice drift period. Ice floes and lateral ice jams annually destroy river banks. As a result of ice jams, river slopes are undercut, then they weather and erode, gradually widening river channels and shallowing the fairway (Volosukhin, Bandurin, 2017).

Ice jams also play a significant role in channel reformation. If a jam forms in the main channel, the ice flow bypasses it, eroding side channels.

Considering all these factors, periodic monitoring of the condition of navigable riverbank slopes and guaranteed fairway depths becomes relevant.

Monitoring the Condition of the Fairway

Each river has a source — an origin, which can be a lake, swamp, glacier, spring, etc., and a mouth — the place where the river ends and flows into the sea, lake, or another river (Volosukhin, Bandurin, 2017).

The water horizon, or river water level, fluctuates from maximum during high water periods, when part of the valley – the floodplain – is flooded, to minimum during low water periods — a low-water state of the river. Maximum and minimum horizons in the river almost annually change depending on the river's feeding. Rivers have more water in snowy and rainy years and less in low-snow and dry years.

River water levels depend on the presence of hydraulic structures, wind-induced surge phenomena, and tides and ebbs at river mouths.

The longitudinal profile of the riverbed has a jagged shape, constantly changing and descending in steps from the source to the mouth. Deep-water sections – pools – are located between sandy shallow sections – shoals. Each river has its longitudinal profile and slope, so the water level varies along different sections of the river. Typically, the upper part – the upper pool – has a steeper slope, the stream cuts through the rock, the flow velocity is high, and the depth is relatively shallow. Navigation on such a river is difficult. For example, the Volga in the upper pool. In the lower pool of the river, the slope is usually minimal, the flow velocity sharply decreases, contributing to sediment deposition in the channel.

The moving river stream continuously finds its way and primarily erodes places where the soil is weak, depositing sediments elsewhere in the form of mid-channel bars, islands, and most often spits. Thus, river bends form, and their erosion intensifies with increased flow around curves. Bank erosion and sediment deposition are especially intense during ice drift.

River bends vary in length and shape (Figure 5). Long bends of the low-water channel together with the valley are called meanders. A very long river bend, where the distance between the start and end is significantly less than the bend's length, is called a loop. A long bend inside the valley is called a meander, and a steep short meander is called a knee. As the river erosion increases, the start and end of the meander may connect during high water periods. This natural straightening of the river is called a chute, and navigation may occur through it during high water and then during low water periods. Over time, the chute becomes deeper and wider and may turn into the main channel. Meanwhile, the meander itself fills with sediments, gradually becoming shallow, turning into an old channel – an oxbow lake or abandoned riverbed.

Considering all the above, continuous monitoring of the fairway condition in the pre-navigation period becomes relevant to ensure shipping channel depth during the navigation period.

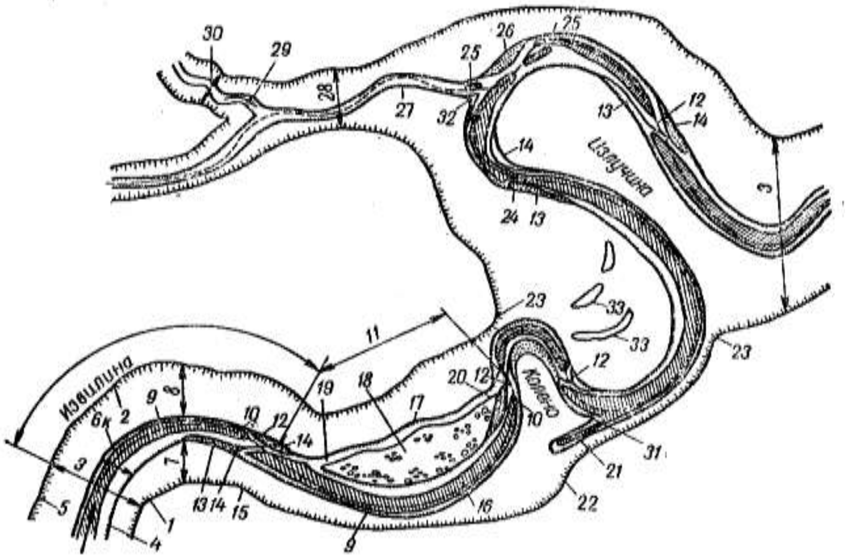

Fig. 5. River bends

Methods of Processing Data Obtained from Sensors

Preparatory filtering algorithm

Data read from sensors undergo primary processing by an Arduino processor to prevent highly noisy data from entering the operational database. Then, in real-time, data is collected and accumulated in the Blender 3D package database to create a three-dimensional computer graphic model (Ponomarenko, Karavaev, 2014; Ametov et al., 2016).

Quality noise filtering can reduce measurement errors and improve sensor measurement accuracy. It is necessary to combat two types of noise: constant noise (additive white Gaussian noise) with relatively stable amplitude and random impulses caused by external factors.

The arithmetic mean method effectively combats random noise, storing several previous measurement values in a buffer. When a new value is added to the buffer at the end of the sequence, the "window" of viewed values moves along it. A drawback of this method is some slowdown in data processing due to the need for floating-point calculations, but these are still faster than data exchange operations, thus negligibly affecting sensor reading speed (Ponomarenko, Karavaev, 2014).

The median filter method is convenient for combating random impulses within a single measurement. Combined with the arithmetic mean method, it yields acceptable results on experimental data.

After preliminary filtering, processed data is transmitted via WiFi to a control computer, where it undergoes more thorough processing.

Primary data processing includes:

– Median filter for combating random impulses.
– Arithmetic mean method.
– Preliminary filtering on-board the drone.
– Optimal filter setup parameters:
– Median filter window size: 5-7 measurements.
– Averaging period: 3-5 seconds.
– Threshold deviation value: 3σ.

Model refinement algorithm

The drone's algorithm for navigating within a water body to refine depths is based on a uniform grid. In areas with significant depth differences, the distances between successive drone trajectories on the water surface are reduced, and intermediate point data is collected. For depth refinement, the drone can be manually directed to any accessible point in the water body. The model constructs the water bed surface using linear interpolation, but before sending the sensor-obtained data to the database for model construction, these data are filtered using the

"Caterpillar" method (SSA) implemented in GNU Octave software (Alekseev, Chesnokova, 2012).

Data transmitted over communication channels are subject to "jitter" — undesirable disruption of signal temporal periodicity. In communication channels, jitter represents oscillation of the information signal's temporal position relative to its nominal value. Jitter in data transmission channels is caused by synchronization instability and path fluctuations. Jitter typically has two components: purely random and quasi-deterministic, usually low-frequency, referred to as "wander" in digital systems (Baklanov, 1998).

Particular interest lies in filtering the quasi-deterministic component, whose presence is mainly determined by the characteristics of the used equipment. To extract this component, the "Caterpillar" time series analysis method is proposed, whose main advantage is the lack of need for an a priori jitter model. "Caterpillar" or Singular Spectrum Analysis (SSA) allows for higher-quality analysis of various time series compared to common traditional methods.

The main goal of SSA is to decompose a series into interpretable components such as trend, periodic components, and noise. The essence of the method is transforming a one-dimensional series into multidimensional using a one-parameter shift procedure (hence the name "Caterpillar"), examining the resulting multidimensional trajectory using Principal Component Analysis (singular decomposition), and reconstructing (approximating) the series from selected principal components. The result of applying the method is the decomposition of the time series into simple components – slow trends and other periodic or oscillatory components, as well as noise components.

After undergoing such a filtering process, data cleaned from noise effects – slow trends – are used to build a 3D model of the water body.

Main stages of implementing the "Caterpillar" (SSA) method consist of four stages:

Stage 1. Embedding Transformation

Embedding is the process of converting certain data into numbers, vectors, which machines can not only store but also manipulate.

The original time series x(t) is transformed into a multidimensional series by creating a trajectory matrix. For this, a decomposition window L (100-200 points) is chosen, and each sequence of L points forms a row vector of matrix X.

Stage 2. Singular Value Decomposition

The resulting matrix X undergoes singular value decomposition: $X = U \Sigma V$,

where U and V are orthogonal matrices, and Σ is a diagonal matrix of singular values. Singular value decomposition can be reformulated geometrically as follows: a linear operator mapping elements of space R^n into itself can be represented as sequentially performed linear operators of rotation and stretching. Therefore, the components of singular value decomposition vividly show the geometric changes when a linear operator A maps a set of vectors from vector space into itself or into a vector space of another dimension.

Stage 3. Component Grouping and Principal Component Analysis

Principal components are identified based on the analysis of singular values. Usually, 3-5 components exceeding the noise threshold of 0.05 are used.

Stage 4. Reconstruction of the Filtered Signal

The filtered signal is reconstructed by inverse transformation of the selected components:

$X^* = \sum(i=1 \text{ to } k)\ \sigma_i u_i v_i^*$,

where k is the number of selected components.

SSA Method Parameters for Implementation in GNU Octave Package:

– Decomposition window length: 100-200 points.
– Number of components for reconstruction: 3-5.
– Noise cutoff threshold: 0.05.

Algorithm Characteristics:

– Adaptability to changes in data.
– No need for preliminary settings for different types of signals.
– High processing speed due to matrix operations.
– Robustness to outliers and anomalies in data.

Quality of filtering is evaluated by the following metrics:

– Noise suppression coefficient.
– Correlation with the original signal.
– Root mean square error of reconstruction.
– Temporal stability of results.

This algorithm ensures an optimal balance between preserving useful information and removing noise components, which is critically important for measurement accuracy during dredging operations.

Modern analogues

Algorithmic compensation of measurement errors is the main method for improving the accuracy of modern monitoring systems. Its implementation requires the synthesis of estimation algorithms, which includes forming a model of the estimated state vector of a dynamic system. The type and order of the model affect the accuracy and quality of the obtained filtered estimates. Various information processing methods are applied to solve the problem of algorithmic error compensation, often using the Kalman filter – an algorithm that estimates the state vector of a dynamic system based on current measurements.

Determining coordinates and corresponding depths with the highest possible accuracy from a sequence of measurements generated by radar or optoelectronic systems is the central task of any monitoring system. A significant number of algorithms have been developed to solve this problem, mainly based on the well-known recursive Kalman filter algorithm, efficiently implemented on digital computers.

However, the problem cannot yet be considered definitively solved. This is due to many factors, and one of the most significant is the nonlinear nature of motion and measurement models in many practical problems. Nonlinearity arises for many reasons — due to nonlinear relationships between coordinate systems used in observation object and measurement equations, or due to the inherently nonlinear nature of the equations themselves.

Ignoring nonlinearities and overly simplifying the situation can significantly reduce the effectiveness of coordinate and velocity estimation algorithms in real target tracking systems. In practice, nonlinear estimation algorithms are used, but mainly limited to simpler variants such as the extended Kalman filter. More powerful algorithms exist but are rarely used because they require significant computational costs. However, the rapid growth of computing capabilities over many recent years quite allows using many of these algorithms in practice.

Comparison with Existing Methods

– **Kalman Filter** – An efficient recursive filter estimating the state vector of a dynamic system using a series of incomplete and noisy measurements. The Kalman filter is designed for recursive estimation of the state vector of an a priori known dynamic system, meaning calculating the current state requires knowing the current measurement and the previous state of the filter itself. Thus, like other recursive filters, the Kalman filter is implemented in the time domain rather than the frequency domain, but unlike other similar filters, it operates not only with state estimates but also with uncertainty estimates (probability density) of the state vector, based on Bayes' conditional probability formula.

The algorithm works in two stages. In the first stage – prediction stage – the Kalman filter extrapolates the state variable values and their uncertainties. In the second stage, based on the measurement data (obtained with some error), the extrapolation result is refined. Due to its step-by-step nature, the algorithm can track the object's state in real-time (without looking ahead, using only current measurements and information about the previous state and its uncertainty) (Shakhtarin, 2008a, 2008b; Egorushkin, Salychev, 2018).

– **Fourier Analysis** – A direction in analysis studying how general mathematical functions can be represented or approximated as a sum of simpler trigonometric functions. Fourier analysis arose from studying the properties of Fourier series and is named after Joseph Fourier, who showed that representing a function as a sum of trigonometric functions greatly simplifies the study of heat transfer. Fourier analysis finds application in solving a wide range of mathematical problems. In science and engineering, decomposing a function into oscillatory components is called Fourier analysis, and operating and reconstructing functions from those parts is called Fourier synthesis. For example, determining which frequency components are present in a musical note involves applying Fourier analysis to the selected musical note. Afterward, the same sound can be synthesized using the frequency components detected during the analysis.

– **Wavelet Transform** – A method that decomposes a signal into a linear combination of shifted and scaled versions of a mother wavelet. Since this is a multi-resolution approach, it provides excellent time and frequency localization of the signal representation. This integral transform represents the convolution of the wavelet function with the signal. Wavelet transform translates the signal from the time domain into the frequency-time domain.

A method of transforming a function (or signal) into a form that either makes some quantities of the original signal more amenable to study or allows compressing the original dataset. Wavelet signal transformation is a generalization of spectral analysis. The term (wavelet) in English translation means "small wave." Wavelets are the general name for mathematical functions of a certain shape that are localized in time and frequency, and all functions are derived from one base function by modifying it (shifting, stretching). Wavelet transform of a function is an improved version of the Fourier transform. Fourier transform is a powerful tool for analyzing components of stationary signals, but it is not suitable for analyzing non-stationary signals, whereas wavelet transform allows analyzing components of non-stationary signals.

Advantages of the proposed SSA approach lie in the fact that the caterpillar method can extract polynomial and exponential trends. Moreover, unlike regression, SSA does not require pre-specification of a parametric model, which can provide a significant advantage when conducting exploratory analysis of a series and there is no obvious model, as happens in monitoring systems. Algorithms based on the caterpillar method possess:

– High data processing speed;
– Adaptability to changing conditions;
– Ease of implementation.

Results of data filtering

The result of the conducted research is the development of a method for performing rapid filtering of field research data on depths and bottom relief of newly formed reservoirs in the drying sea or river basin.

Quantitative indicators:

– Noise reduction: 40-50 %;
– Measurement accuracy improvement: 25-30 %;
– Data processing time: 0.2-0.3 seconds.

Comparison with traditional methods:

– Accuracy is 15-20 % higher compared to simple averaging;
– Processing speed is 2-3 times faster than Kalman filtering;
– Stability of results under various conditions.

Quality of filtering is evaluated by the following metrics:

– Noise suppression coefficient;
– Correlation with the original signal;
– Root mean square error of reconstruction;
– Temporal stability of results.

This algorithm ensures an optimal balance between preserving useful information and removing noise components, which is critically important for measurement accuracy during dredging operations.

4. Results

The developed method of rapid data filtering improves the efficiency of fairway parameter measurements and thereby increases the accuracy of dredging work planning by 15-20 %. Implementation of the proposed methodology provides:

– Increased accuracy of bottom relief measurements;
– Reduced influence of external interference;
– Accelerated data processing;
– Improved quality of created 3D models of reservoirs.

The proposed approach can be successfully applied in real conditions to optimize the process of water area monitoring and dredging work planning.

5. Conclusion

The result of the conducted research is the development of a method for monitoring and rapidly visualizing field research on depths and bottom relief of the fairway, as well as the state of coastal slopes of the shipping channel and quay walls.

The presented method of rapid monitoring with simultaneous visualization of field measurements, cleaned from noise, data on depth and bottom relief and coastal slopes of the shipping channel, as well as the state of piers and walls of hydraulic structures in the post-flood period of the river, can be used for designing restoration and dredging works and can increase their efficiency by 15-20 %.

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