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Mitigating the Negative Impacts of Caspian Sea Level Fluctuations On Coastal Infrastructure

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Abstract

Natural fluctuations of the Caspian Sea level create many problems for its coastal infrastructure, complicate navigation and fishing, and negatively affect the ecological situation both in the coastal zone and in the coastal water area. It is necessary to deal with a complexity in a sea area alteration very carefully in order not to destroy the fragile ecological balance of coastal flora and fauna. To reduce the negative consequences of a northern water area shoaling of the Caspian Sea, a dredging is constantly carried out, which requires a careful planning due to a constant variability of the sea area boundaries. Taking into account this fact, the problem of permanent monitoring of newly formed closed water bodies with the help of autonomous water drones that allow to quickly build a 3d model of the water body for dredging planning becomes urgent. As a rule, such bodies of water are formed far from large settlements and energy sources, and the process of surveying the water body can stretch in time, so the problem of recharging the batteries of the drone becomes very relevant and is solved with the help of solar panels. The data received from the distance sensors can be noisy, so they are subjected to a de-noising procedure.

Keywords: Reducing the level of the Caspian Sea, maintaining shipping and fishing, maintaining the ecology of the coastal zone, dredging, Arduino robotics, autonomous water drones, recharging batteries with solar panels, cleaning received data from noise, volumetric model of a reservoir, freely distributed software.

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1. Introduction

The Caspian Sea is essentially an isolated inland water body – a lake – and has no outflow to the World Ocean (Figure 1). This isolation and dependence on the volume of runoff from rivers flowing into it is a reason for significant fluctuations in its water level and, as a consequence, for environmental problems and problems in the operation of coastal infrastructure (Samant et al., 2023; Pörtner et al., 2022). If the water level drops significantly, shoals appear and impede navigation and fishing; if the water level rises, flooding of coastal areas becomes a problem (Prange et al., 2020; Hollis, 1978). Long-term water level fluctuation observation in the Caspian Sea demonstrates periodic long-term increase or decrease in a water level, which are a natural process that must be adapted to minimize the damage caused (Akbari et al., 2020; Pekel et al., 2016; Kislov et al., 2014; Efimov et al., 2015).

Fig. 1. Relief of the Caspian Sea area

The Northern Caspian Sea is a powerful navigable artery connecting the states on its shores with sea and river ports of the European part of Russia, a large volume of cargo operation is transported through its, therefore, maintaining the proper condition of waterways, including their sufficient depth, is of strategic importance for the whole country. In recent years, there has been a sharp drop in the level of the Caspian Sea, which leads to siltation and the formation of shoals and isolated water bodies in place of its former water surface, which greatly complicates the work of the shipping and fishing industries of the coastal territories (Grishanin, 1979; Shipulin, 2024; PRONauka, 2024; Samant, Prange, 2023; Demin, 2007).

Hydrological studies show that the main causes of the Caspian Sea shallowing are climate change and anthropogenic impact (Wang et al., 2018; Healy et al., 2007). While the global sea level is rising due to melting glaciers and expansion of warm water, the Caspian Sea, being a closed body of water with no outflow to the ocean, reacts to local climatic conditions (Koriche et al., 2021; Arpe et al., 2000). An increase in air temperature leads to an increase in evaporation, while a decrease in precipitation reduces the inflow of river water (Chen et al., 2017; Mischke, 2020). Reduced water surface area leads to degradation of coastal ecosystems, disappearance of marshes and deltas, which provide habitat for many species of birds and fish. Unique species, such as Caspian seal and sturgeons, are threatened by habitat reduction and changes in the food chain (Aliyev, 2024).

The regulation of river flow and the resulting drop in water levels in the Caspian Sea has led to changes in natural biogeochemical cycles (Berkeliev, 2024).

Massive hydro construction on the Volga and then on other rivers of the Caspian basin has deprived Caspian sturgeons of most of their natural spawning grounds. Fish passage structures at the dams suffer from many technical deficiencies, and the system of counting spawning fish is also far from perfect. However, with the best systems, the juvenile fish rolling down the river will not return to the sea, but will form artificial populations in polluted and food-poor reservoirs. It was dams, not water pollution and not overfishing, that were the main reason for the reduction of the sturgeon herd. Meanwhile, the construction of dams has caused even greater problems. The Northern Caspian was once the richest part of the sea. Here, the Volga brought mineral phosphorus (about 80 % of the total input), providing the bulk of primary biological (photosynthetic) production. As a consequence, 70 % of sturgeon stocks were formed in this part of the sea. Now most of the phosphate is consumed in the Volga reservoirs, and phosphorus enters the sea in the form of living and dead organic matter. As a result, the biological cycle has changed radically.

The Ural remains the only unregulated major river in the Caspian basin, but the condition of spawning grounds on this river is also very unfavorable. The main problem today is siltation of the riverbed. The soils in the Ural valley were once protected by forests; later these forests were cut down and the floodplain was plowed almost to the water's edge. After “for the purpose of sturgeon conservation”, navigation was stopped on the Ural River, work on cleaning the fairway ceased, making most of the spawning grounds on this river inaccessible.

Active dredging to facilitate the movement of water masses to the main sea area can mitigate the negative effects of these phenomena. Dredging can be initiated after monitoring the boundaries and depths of the resulting isolated water bodies. Dredging is continuously carried out to control siltation and sedimentation, thus reducing the length of one-way traffic areas and constructing protection structures against siltation and shallowing. To survey such areas, autonomous water drones can be used, which will operate under the control of a program loaded in them and transmit information to a stationary computer that forms a 3d-model of the geometry and depths of the water body. In order to predict the occurrence of difficult areas and design dredging works, it is necessary to continuously monitor channel processes and calculate sediment loadings.

This work is devoted to predicting and mitigating environmental, shipping and fishing problems in the coastal areas of the Northern Caspian Sea, which arise due to its level lowering.

Formally, the task can be formulated as follows: to create a robotic solution that can move on the surface of a reservoir, create its 3D model and track its position in real time.

2. Materials and methods

To solve the presented task, we use Arduino controller and compatible sensors. Robotics compatible with Arduino controller has good technical parameters and there is a free software Arduino IDE. Arduino controllers are quite budget-friendly compared to their counterparts: Teensy, Particle Photon, BeagleBone.

We use Arduino Uno as a main controller board (Figure 2). The controller is equipped with an ATmega328 microcontroller and operates at 5 volts. It has 14 digital I/O, of which 6 support PWM, and 6 analog inputs. The maximum current from a single I/O pin is 40 milliamps. Flash memory has a capacity of 32 kilobytes. RAM is two kilobytes and EEPROM is one kilobyte. The controller clock frequency is 016 megahertz. The board has dimensions of 69×53 mm and is equipped with a USB-type A-B connector.

The robot must be able to move on the water surface while maintaining stability and minimizing oscillations. The robot body will be made of foam for good buoyancy. To prevent rollovers, we will use the MPU-6050 gyroscope and accelerometer sensor. The sensor has small dimensions of 21×16×3 mm, weighs about 10 g, operates at 6 VDC consuming 350 mA. Gyroscope range is ± 250; 500; 1000; 2000 °/s, accelerometer range is ± 2; 4; 8; 16 g.

The robot moves with the help of two motors with screws. The motor dimension of 70×22×18 mm is small, weigh is about 50 g, it operates at a voltage of 6 v, consuming up to 500 mA. And as a rotary mechanism we will use a servo drive, it will direct the propellers in the desired direction. The MG946R servo drive has small dimensions of 43×40.7×19.7 mm, weighs 55 g, operates at a 4.8-7.2 VDC consuming up to 1.2 A.

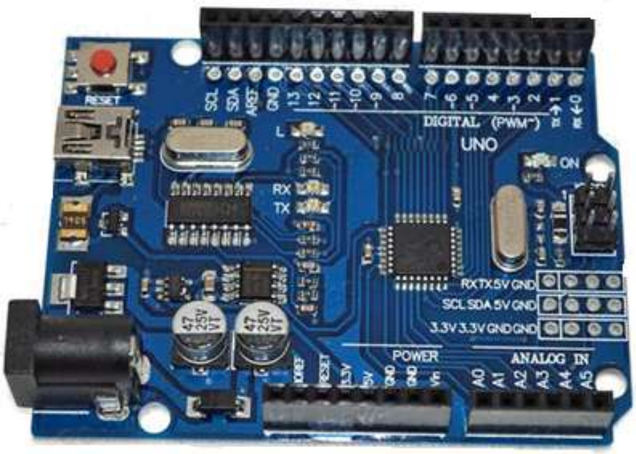

Fig. 2. Arduino Uno board

The system must be able to collect data on a depth and a shape of the bottom as well as the contours of the tank walls. A waterproof ultrasonic sensor JSN-SR04T is suitable for a depth measurement. The sensor has small dimensions of 41×28.5×28.5 mm, weighs about 8 g, operates at a voltage of 5 VDC, consumes 5 mA, ultrasonic frequency of 40 kHz, measured range up to 4.5 m with an accuracy of 0.003 m. We use the HC-SR04 ultrasonic sensor to recognize the boundaries of the tank. The sensor also has small dimensions of 45×20×15 mm, weighs about 10 g, operates at a voltage of 5 VDC, during standby consumes 2 mA, during measurement consumes up to 15 mA, ultrasonic frequency of 40 kHz, measured range up to 4 m with an accuracy of 0.003 m. A 3D model will be created from the received data. For data transmission we use Bluetooth sensor HC-06. The sensor has small dimensions 27×13×2.2 mm, weighs about 15 g, operates at a voltage of 3.3-5 VDC, consumes 50 mA, the range is up to 10 m.

The robot must track its location in the tank and transmit it in real time. For this task, we use a GPS sensor. The sensor has dimensions of 21×16×3 mm, weighs about 18 g, operates at a 4.4 VDC, consumes 45 mA, and has a location update rate of 5 Hz. The robot will be powered by two LiitoKala inr18650 batteries with a capacity of 2500 mA-h and a voltage of 3.7 VDC.

The water bodies formed as a result of the retreat of the Caspian Sea water area may have different geometric dimensions and depth, which will require their long-term survey, may be located at a considerable distance from the established coastline, where the infrastructure for recharging batteries is located, so in addition to providing the possibility of recharging them from the power-bank, it is still useful to provide for the possibility of using solar energy to ensure the operation of the robot through autonomous power supply. The most efficient use of the solar panel can be achieved by using an Arduino board that tracks the location of the sun (following the sun) in order to maximize the amount of energy generated by the solar panel (since it will always be turned towards the light) (Bard et al., 2000). The components required are Arduino Uno board, sg90 servo motor, solar panel, photoresistor (2 pcs), 10k ohm resistor (2 pcs), battery. Here the photoresistor will work as light detector and when light starts falling on the photoresistor, its resistance decreases, that's why the photoresistors are often used in various light or darkness detectors.

Two photoresistors are placed at the both ends of the solar panel and a servo motor is used to rotate the solar panel. The servo motor rotates the solar panel towards the photoresistor whose resistance is lower, which means that more sunlight is falling on it. If the same amount of sunlight falls on both photoresistors, the servo motor does not work and does not turn the solar panel. So the servo motor will try to rotate the solar panel to a position where both photoresistors have approximately the same resistance, which would mean that they receive approximately the same amount of sunlight. If the resistance of one photoresistor becomes less than that of the other, then the servo motor will rotate the solar panel in the direction of that photoresistor. In this solar panel following the sun design, the Arduino board is powered by a 9 VDC battery and the rest of the circuit is powered by the Arduino. The recommended voltage for powering the Arduino board is between 7 and 12 VDC (although you can actually supply between 6 and 20 VDC), so our 9 VDC is well within the recommended range.

If the solar panel is rotated to follow the sun, the efficiency of its operation will be higher than if it just stays in a stable position. However, a correction should not be done too often, so that the increase in efficiency is not reset by the corrector motors.

The market of microcontrollers offers various variants of solar panels for Arduino-products, which can be used both jointly and separately. Besides, it is possible to assemble an angular battery from the panels, and if you fold it in a triangle, part of the panels will “look” to the east, part – to the south, part – to the west. So that it will not be necessary to rotate the battery, and all the power of solar energy will be used not to solve auxiliary problems, but to solve the main task.

The data obtained from the sensors are collected and accumulated in real time in the database of Blender 3D package – a freely distributed software package for creating 3D computer graphics, which are used for 3D modeling and visualization in various spheres of activity.

When receiving a digital signal from sensors, the problem of its purification, i.e. separation of the active signal from noise, is acute. A signal received from the sensors always comes with noise, and it is important to be able to filter it properly. Good quality noise filtering can reduce the error and increase the quality of the sensor measurement.

Two types of noise are commonly attempted (Figure 3):

– Constant noise (additive white Gaussian noise) with relatively stable amplitude and

– Random pulses caused by external factors.

The noise amplitude is the standard deviation of the noisy signal from the unnoisy signal.

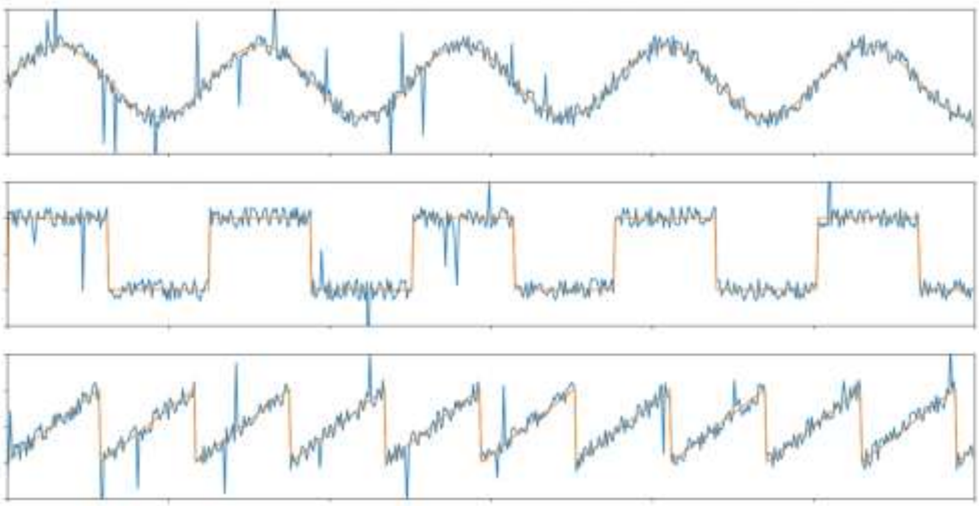

Fig. 3. Cleaning a noisy signal

The simplest filtering method is to filter the graph using the arithmetic mean method (Bukhtiyarov, 2021). The algorithm of this method is quite simple – it will require a buffer of several previous values, each time a sensor is polled, the buffer will be shifted (the first element is removed and the new sensor value is added to the end). The size of the buffer will determine the result and the speed of the code. The algorithm does very well with filtering, but its problem is the loss of performance because the controller has to do a lot of floating point calculations, which can affect the speed of code execution. If the sensor is not polled very often, this method copes with the task perfectly well, the main thing is to have a fixed buffer size.

With random impulses the median filter copes well, which is easy to implement and in combination with the arithmetic mean method gives quite a decent result.

To create a 3D model, we will use the free publicly available software Blender. Indicators from sensors will be converted into coordinates and written to obj file using the following libraries: FS.h and LittleFS.h. The FS.h library is needed to process the file, and LittleFS.h is needed to create and access the file system. Then, if we open the file, we can see a model of the tank.

Initially, the robot is placed on the edge of the tank and moves a short distance away from it (15-20 cm to be able to turn without touching the edge of the tank). The robot should walk around the edge of the tank at a short distance from the edge, collecting route coordinates and measured depths while building a 3D model of the tank edges. After that, the entire surface of the reservoir should be explored using the uniform grid method, instantiating the depths of the reservoir in the 3D model. The robot's movement can then be controlled from the remote control, displaying the route of its movement in the 3D model.

3. Results and discussion

As a result of the performed research, the project of a robot – an aquatic drone, which performs the survey of water bodies newly formed during the retreat of the Caspian Sea water area, was built. The robot examines the geometry of the water body banks and its depth, promptly transmits the information to the associated computer, which cleans the noise data and builds a volumetric model of the water body in a free 3D-modeling package, and allows to build a dredging plan. The robot's design includes the use of solar panels to recharge the robot when conducting long-term studies.

4. Conclusion and recommendations

The proposed robot project for monitoring of newly formed compact water bodies in the place of the former Caspian Sea water area when its level decreases will allow building a dredging project to ensure the necessary conditions for navigation and fishery.

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