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Concept of using unmanned aerial vehicle (UAV) in the analysis of traffic parameters on Oder Waterway

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Abstract

The aim of this paper is to develop a concept of using video materials obtained from unmanned aerial vehicle in the survey of cargo traffic parameters on inland waterways. The analysis was carried out on the example of the navigational sensitive sections of Oder Waterway within the Szczecin agglomeration. The concept provides an analysis of the passing of the push-tag set under the bridges and the winding sections of the Oder River. The study used a simulation model of inland waterway traffic based on information provided from a camera installed on an unmanned aerial vehicle. This paper presents the methods of using modern technologies of acquiring, processing and analysing video materials of passing inland waterway units. The other aim of the article is to propose possible scenarios for the use of IT methods known from other modes of transport and to indicate the differences and threats related to the specific nature of water transport.

Keywords: inland shipping; transport; image analysis; UAV;

1. Introduction

According to the growing number of transport and recreational vessels on European inland waterways, ensuring the safety of shipping is becoming more and more important. Places most exposed to collisions are primarily the intersection of waterways with road and rail infrastructure, in the form of bridges and viaducts. Collisions with the participation of inland waterway vessels creates a threat not only in a river transport, but to the users of other transportation systems like road, tram or pedestrian. The costs of possible consequences of ship collision with the bridge are also important. In the region of the Regional Water Management Board in Szczecin (RZGW), an average

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of 1 collision vessel with a bridge is recorded annually. One of the major collisions in 2001 was the collision of the ship with the span of the railway bridge in Szczecin, which caused the destruction of the bridge guides and, as a result, the need to replace them. In the section covered by RIS (River Information Services), from 697 kilometres of Odra River in the town of Ognica to the sea level, there are 21 bridge crossings. The specific bridge that we can distinguish is the railway bridge at Dworcowa Str. The bridge was originally built in 1868. It was destroyed during World War II and rebuilt in the early 1960s. The bridge supports are lined with guide rails that have been designed for right-hand traffic. Experimentally, in 2013 and 2014, left-hand traffic was introduced under the railway bridge, which was to facilitate manoeuvring with long pushed sets. This idea was abandoned in September 2014. Such changes, even for experienced captains and navigators, constitute an additional element that hinders navigation in this region.

Ensuring the safety of inland waterway transport within urban agglomerations also indirectly influences the improvement of the safety of traffic participants of other transport branches. The importance of inland waterways transport and the impact it has on transport within urban agglomerations cannot be overestimated. Possibilities of transferring goods transport even on minor distances have a positive impact on such phenomena as reducing air pollution with harmful substances, reducing congestion in cities and its bypasses. Definitely river transport can be considered as the "greenest" among branches using traditional energy sources. The standard motor barge is able to take 20 fully load 20-foot containers simultaneously. Undoubtedly beneficial effect on increasing the interest in this branch of alternative transport is to equip the entire process with modern techniques that will improve safety and facilitate the organization of the transport process. Several scenarios will be presented in this manual as it can be done.

Management and monitoring of vessel traffic in waters covered by harmonized river information services takes place through the collection, analysis and distribution of information from various sources. This is to improve transport safety and improve the efficiency of inland waterway transport. The technical specifications for vessel traffic control systems on inland waterways covered by the RIS shall take into account the technical requirements for the operation of the system. These include: a system for displaying electronic maps and information in inland navigation (ECDIS inland); electronic ship reporting system via the inland automatic identification system (AIS); radio information service; ship positioning system with an appropriate degree of accuracy and integrity; radar traffic control systems and vessel monitoring systems.

Due to the fact that there are no regulations that force captains to equip inland vessels with all of the aforementioned facilities, there is a need to create an additional source of information on the passing inland vessels. Numerous scientific papers deal with the analysis of images, in particular in the transport of utility vehicles and pedestrian traffic (Bashir & Porikli, 2006; Forczmański & Seweryn, 2010; Li, Liang, & Zhang, 2014; Mazurek & Okarma, 2012; Olszewski, Czajewski, Dąbkowski, & Szagała, 2014; Regazzoni, Fabri, & Vernazza, 1999; Vasco Dantas dos Reis, 2014; Viola & Jones, 2001). It is possible to use some of the algorithms used to recognize objects in motion also in the transport of vessels with certain restrictions The publication (Kujawski, 2015) presents the concept of using surveillance cameras for vessel traffic analysis. Another option is to use of unmanned aerial vehicles (UAV) to monitor the condition of waterways and the parameters of inland waterway traffic. This article presents the concept of using UAV focusing on the possibilities and limitations of such a system.

2. Methods for analysing images obtained from UAV

To determine the trajectory of objects in motion using a camera mounted on the UAV, image processing algorithms can be used so that the analysis takes place without human participation. The multitude of image processing algorithms that are used in various areas of life forces to think about which methods to choose and implement to correctly and quickly process and analyse the video image. The answer is not unambiguous. The algorithms used in road transport differ from the algorithms used in aviation or medicine. To make the right choice, you must define the initial conditions and define what you want to achieve and what problem to solve in the final stage. Under certain conditions, it is possible to rely on studies carried out in road transport. Image analysis in road transport is mainly used for counting passing vehicles in management of traffic systems (Forczmański & Seweryn, 2010; Pamuła, 2012, 2013), as well as for detecting collisions and traffic congestion as well as for recognizing license plates (Chang & Chen, 2004; Okarma, 2014; Sun, Bebis, & Miller, 2006). The specificity of road traffic, construction of vehicles and their speed of traveling on the road determines the choice of image analysis algorithms. These algorithms must meet equal criteria of reliability and speed of operation in real time.

Not all algorithms used in road transport can be directly adopted in water transport, particularly in the transport of vessels operating in inland waterways. Objects moving across water are much larger than road vehicles and there is a large diversity in the dimensions of individual units. Yachts, boats and motor boats can reach from a few to several dozen meters in length, while pushers, motorboats and whole pushed sets are within a range of a dozen or so to over a hundred meters in length. Such a variation in the size and speed of movement of individual units on the water determines the choice of image processing algorithms. Water, on which the units move, generates much larger reflections than the black road surface, and the colour of the water surface depends on the degree of insolation. A feature that hinders the analysis of images on inland waterways is the fact that the water will take different shades depending on the lighting conditions and it will often be a colour similar to the colour of the sky.

Another approach similar to road transport systems is the use of telematics (Iwan, Małecki, & Korczak, 2013; Małecki, Nowosielski, & Forczmański, 2017). The use of intelligent transport system methods in water transport, as well as image analysis methods, is possible under certain conditions taking into account the specificity of transport of inland vessels. The video material acquired for research covers a large area of analysis. The unmanned aerial vehicle was suspended at an altitude of 150 meters and covered the image with a radius of 2 km. Such technical specification of the obtained material and the specific nature of water transport narrows the application of a wide range of methods known from other modes of transport. The use of counting methods for flowing units with UAV utilization is pointless considering the frequency of ship traffic to the river. A one-off study covering a time of about 100 min of analysis allows to examine on average 3 transitions of an inland unit. What is possible is acquiring ship traffic parameters and analysing the unit's path in the vicinity of critical navigation points.

As former research has shown (Kujawski, 2014b, 2014a; Kujawski & Stępień, 2017), the most effective method in terms of the relation of processing speed to accuracy is the Camshif algorithm. This method is an extension of the MeanShift method described in (Fukunaga, 1990). The MeanShift method is suitable for static probability distributions. For dynamic distributions, such as we deal with in video sequences, it is necessary to use the CAMShift (Continuously Adaptive Mean Shift) method, which is able to handle the dynamic distribution by adjusting the size of the pixel search window for each consecutive picture frame. The algorithm is based on the distribution of colors. Creates a histogram of the image of the object being examined, determining the probability function. This function is obtained by projecting the H component to the image plane for the HSV (Hue Saturation Value) model (Bradski, 1998). With its help, an image is determined, where only the pixels are left, for which the value of the probability function is large enough. The common point of both algorithms is to determine the centre of the circle of the searched surroundings of the object in motion.

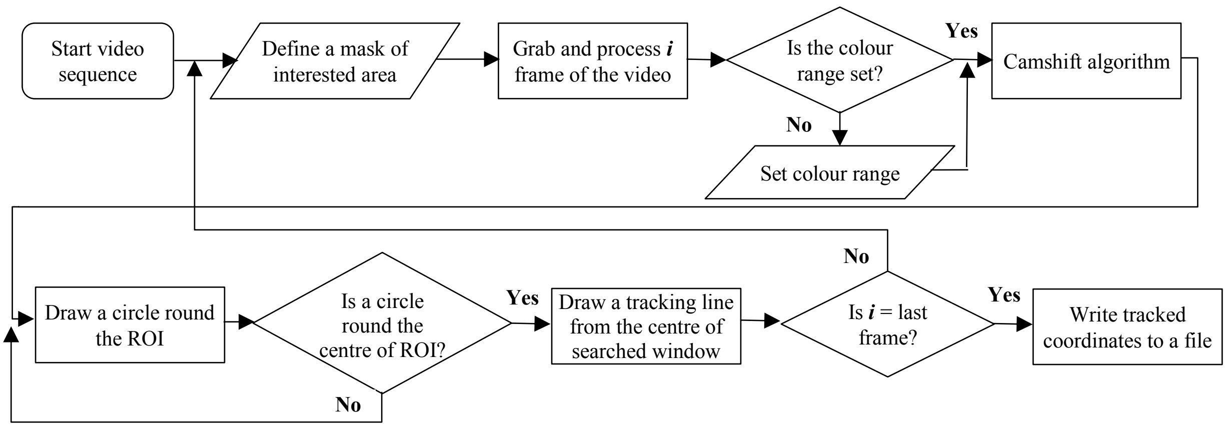

Fig. 1. Recognizing and tracking moving object algorithm.
Source: own study

For discrete image probability distributions, the mean location of the centroid is found as follow:

$$M_{00} = \sum_x \sum_y I(x, y); \tag{1}$$

Find the first moment for x and y:

$$M_{10} = \sum_x \sum_y xI(x, y); \quad M_{01} = \sum_x \sum_y yI(x, y); \tag{2}$$

Mean search window location (the centroid) is found as:

$$x_c = \frac{M_{10}}{M_{00}}; \quad y_c = \frac{M_{01}}{M_{00}}; \tag{3}$$

where:
M_{00} - zeroth moment;
M_{10} - first moment for x;
M_{01} – first moment for y;
$I(x, y)$ - pixel probability value in the position (x, y) in the image, and x and y range over the search window;
x_c, y_c – the centroid coordinates x, y of searched window.

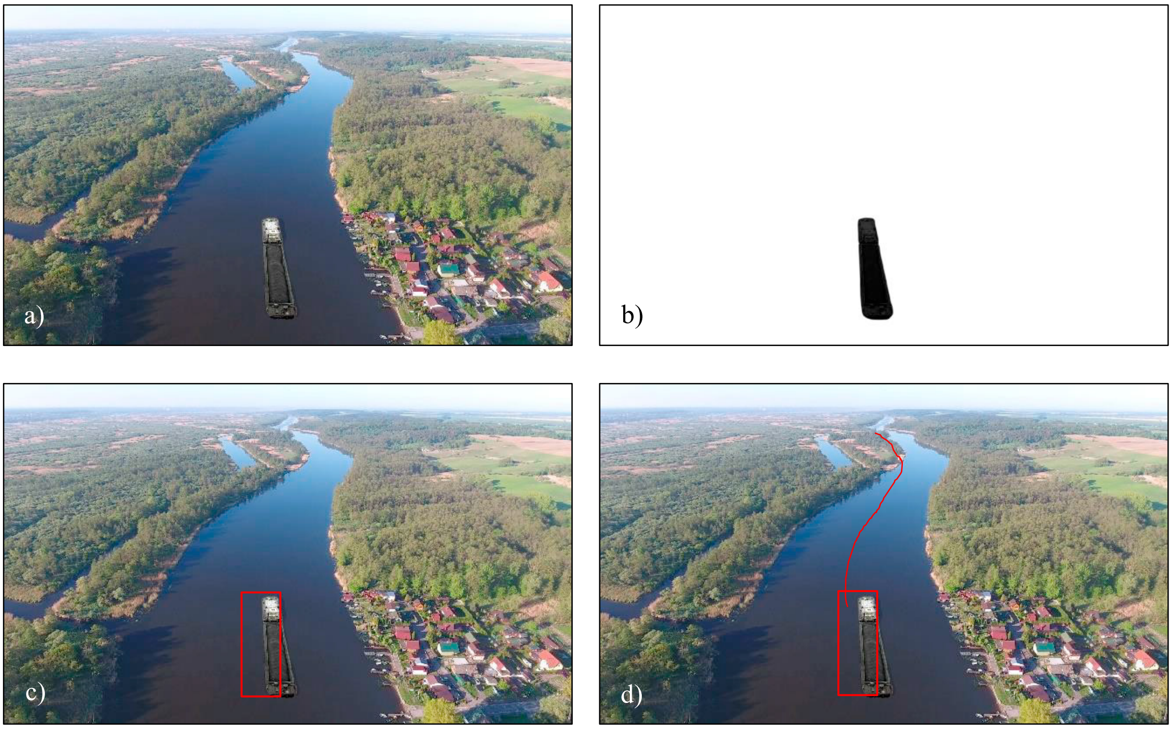

Fig. 2. Determining track line of moving objects during the analysis process. a) original picture; b) background subtracting on moving object; c) moving object detection; d) drawing tracking line
Source: own study

The parameters of the images obtained from the camera mounted UAV (DJI Phantom 4):

Dimensions: 3 840 x 2 160 pixels
Overall bit rate: 60.0 Mb/s
Format/Info: Advanced Video Codec
Format profile: High@L5.1
Display aspect ratio: 16:9
Frame rate: 29.970 (29970/1000) FPS
Color space: YUV
Bit depth: 8 bits

Location:
23 kilometre of West Oder River
Long: 53.322827 / Lat: 14.474711
Height: 150m
Direction: South

The subject of the research was the movement of inland vessels on the lower section of the Western Odra River in the area around Moczyły near Szczecin. The passing ships were recognized automatically during the video image analysis process using the Camshif algorithm. This algorithm was a component of the author's method of detecting, tracking and determining the trajectory of a moving object using the algorithm from Figure 1. UAV flights were conducted at different times and different lighting conditions. The analysed direction of the river was both southern and northern. The data from the materials obtained is primarily the empty route, time and distance of the inland waterway passage. From direct observation, it was possible to determine the type of inland waterway unit and the kind of transported cargo. These data can be used as input data for the proposed dynamic system model as well as for modelling simulations using elements of virtual reality.

3. Virtual reality possible scenarios

A large number of currently used unmanned aerial vehicle will be fitted with a variety of sensors ideal for solving multiple tasks (exploration, inspection, mapping, etc.). Remote control and acquisition of data from those sensors is usually carried out by portable devices such as tablets or smartphones, which have many limitations and often negative affects the cooperation with the drone. The increase in the capabilities and scope of UAV require application of new control methods. The emergence of new solutions such as augmented reality (AR) or virtual reality (VR) should improve this situation. It should open new possibilities of drone controlling and data visualization.

Augmented reality is an idea of displaying a real environment image supported by computer-generated objects or information (Fig.3).

Fig. 3. Augmented reality example
Source: blog.proto.io/4-reasons-every-ux-designer-get-virtual-augmented-reality

Such kind of objects may exhibit constructive features (addition to a real environment) or destructive (change, conceal real elements). The technology of augmented reality changes the perception of reality. More and more global enterprises participate in the development of AR and VR technology. Virtual reality (VR) on other hand is a technology of replacing reality with objects created by a computer system. VR tries to simulate the physical presence of the user in a artificial environment, acting as both a special input device and a specialized output device.

The first function is possible thanks to many sensors used to determine the current position and orientation of the user or the object they control (this information can be used in a specially created application). VR used as an output device, on the other hand, gives the possibility of widening the field of view, presenting a computer-generated environment, while at the same time isolating the user from external impulses.

Recent appearance of such sophisticated and extensive technology sets opens a new possibility for VR – drone cooperation (Fig. 4).

Fig. 4. Possibility for VR – UAV cooperation
Source: Own study.

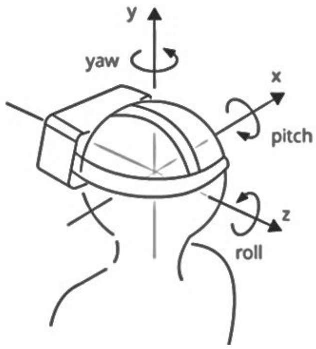

Fig. 5. Position control with VR
Source: (Vermassen, 2016)

The use of these solutions gives the operator the impression of a physical connection with the drone (e.g. controlling its position by head movement, Fig. 5).

It must, however, allow switching between different types of control (the connection is not universal). There are many different types of drones and many VR devices. Due to this diversity, appropriate types of feedback are required, software combining these two solutions (for example applications such as OculusDrone † or Ardronewebflight‡). Applications responsible for drone and VR operation and their optimal cooperation require a specialized approach.

Their role is to define and prepare the base for the appropriate data and work flows (Fig.6.) ensuring joint operation (the ability to implement the required device) of these two technologies (adaptation, propagation of appropriate requests).

† Araos D., "OculusDrone: a web interface to control the AR Drone 2.0 with an Oculus Rift." 2014. https://github.com/daraosn/oculus-drone

‡ Eschenauer L., "Ardrone-webflight: pilot the AR.Drone 2.0 directly from your browser." 2016. :https://github.com/eschnou/ardrone-webflight

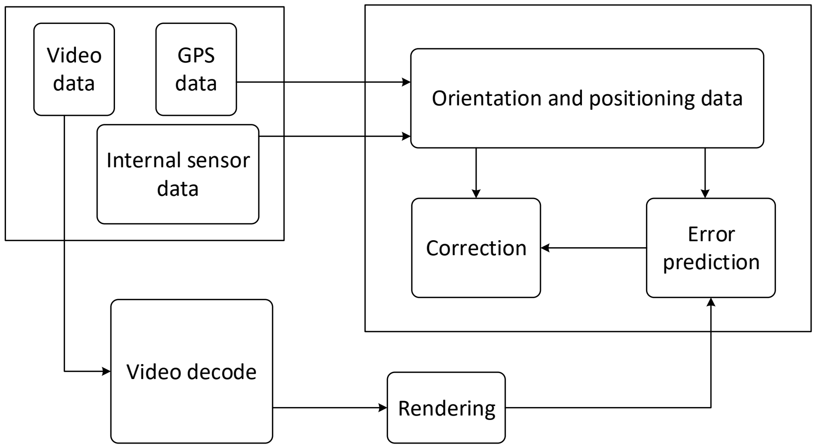

Fig. 6. Data flow for real time VR – UAV system
Source: www.cse.wustl.edu/~jain/cse574-10/ftp/reality/index.html

The architecture of the drone application is responsible on the one hand for the support of specific functionalities related to the UAV service (physical control methods, methods of requesting data from sensors and tools for reading the status of a drone) and on the other hand responsible for interaction with VR. In the case of an application that supports VR, the main modules are those responsible for rendering, data acquisition and control or interaction with UAV. The bonding element - Connection Module is responsible for data transfer between those two applications (Fig.7).

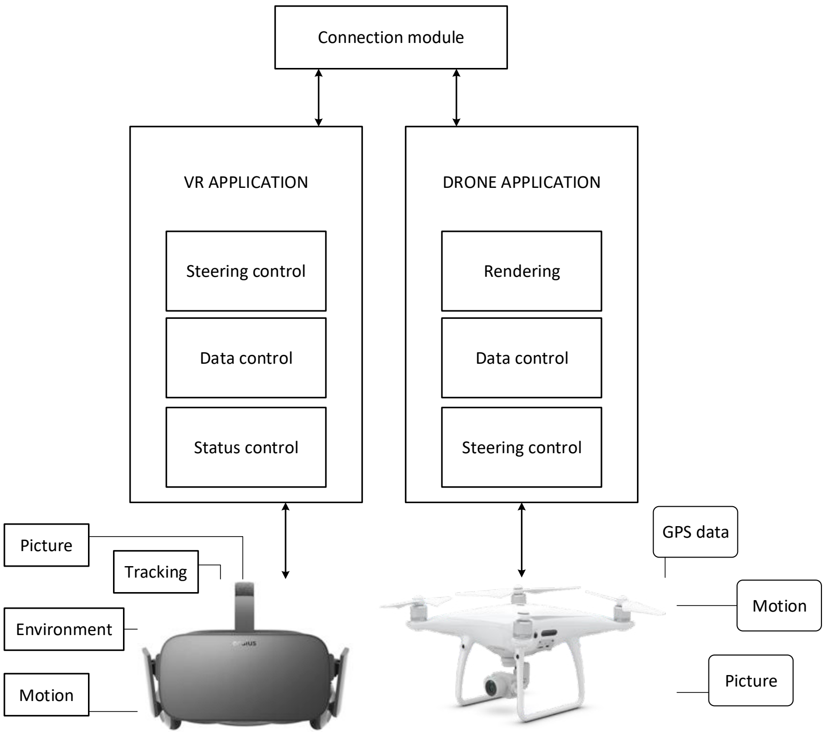

Fig. 7. VR - drone environment architecture
Source: Own study.

Properly prepared software should be able to give the operator real time control over the drone. It should enable UAV tracking in real time and the ability of immersion in the environment generated by its cameras. The delay in displaying the content should be less than 0.5 seconds, the rate of displaying 30 frames per second, and the resolution 1080p (this is the result acceptable to the actual application). VR has the potential to become an efficient user interface for UAV systems.

4. Using System Dynamics

Theoretical foundations of system dynamics were developed by J. W. Forrester and his associates from the Massachusetts Institute of Technology at the turn of the 1950s and 1960s of the last century. Forrester stated that the operative research common at that time, due to the use of a mathematical apparatus allowing only the analysis of linear relationships, did not cope with a new problem for research on organization issues. A tool was needed to observe feedback in complex systems (Rokita, 2011). Defining the principles of building a systemically dynamic model, Souček likened the systemic relations to the system of connected vessels, where streams flow from one to the other as to the reservoir, the size of which depends on the decisions made periodically (Łatuszyńska, 2008; Soućek, 1979). Such a mechanism is called a closed loop of feedback. In systemic dynamics, the effect of model conceptualization is the causal loop diagrams and stock and flow diagrams (Fig. 8).

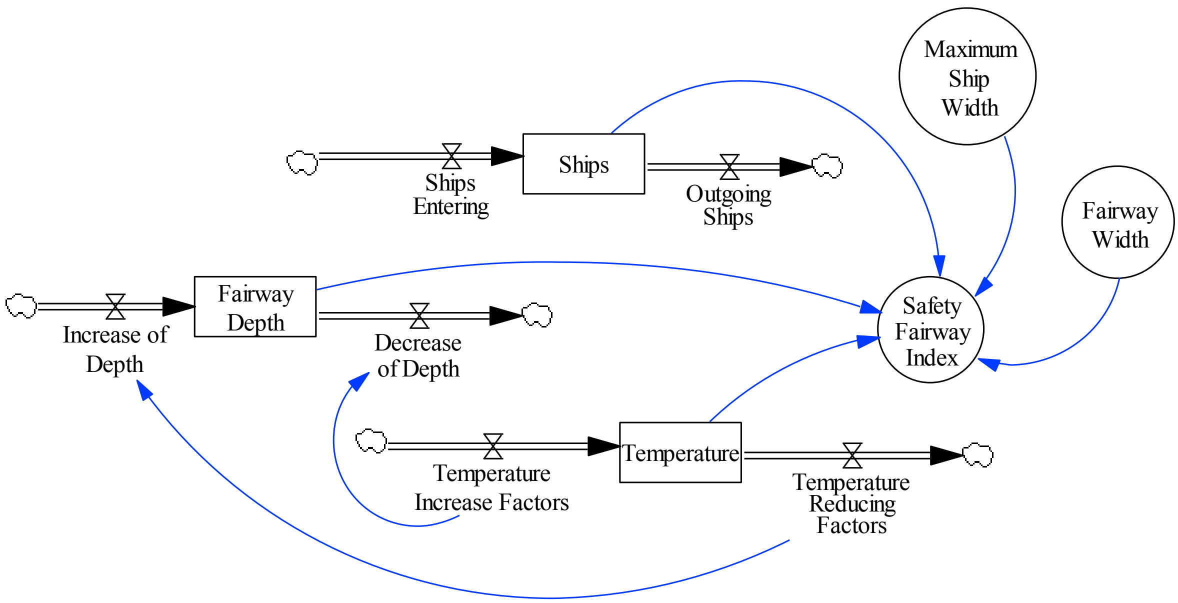

Fig. 8. Example of stock and flow diagram safety of inland fairway model
Source: own study

It should be mentioned that the causal loop diagrams have the task of translating the general idea of the real system into a graphic model. They make it easier to identify variables and relationships between them, but this does not allow the development of a mathematical model. A kind of relationship to the mathematical model are the stock and flow diagrams. It's based on the causal loop diagrams, and their creation consists in defining the mentioned levels and streams, with streams indicating the speed at which the levels are powered (Kasperska & Słota, 2000). In practice, the creators of models use the software available on the market. Selected software has been discussed, in the work of Maciąg and others (Maciąg, Pietroń, & Kukla, 2013). This in turn offers a more or less rich library of graphic symbols used. Behind individual symbols there is a set of parameters or patterns that must be defined in order to be able to perform a computer simulation. For the system dynamic mathematical model, it is characteristic to use difference and differential equations to calculate the level values in successive units of time (Biniek, 2002). The differential solution is the level function, which is presented in equation 4 (Maciąg et al., 2013).

$$Stock_t = \int_{t_0}^{t} (v_t - w_t)\,dt + Stock_{t_o} \tag{4}$$

where:
t – time of end the simulation;
t_o – time of begin the simulation;
dt – period between t_0 and t;
$Stock_t$ - Stock value in time t;
$Stock_{to}$ - Stock value in time t_o;
v_t - Input flow value in period dt;
w_t – Output flow value in period dt.

At the same time, it should be mentioned that the integration in system dynamics can be carried out according to the Euler or Runge-Kutta method. The subject of the accuracy of these integration methods in system-dynamic models was discussed, in Kasperska's paper (Kasperska, 2005). Despite the original application of systemic dynamics to the study of economic systems, there are now system-dynamic models of technical facilities. An example of this is the ship's steam boiler model (Dvornik, 2016; Dvornik & Dvornik, 2007).

The SD model shown at figure 8 presents the concept of fairway safety evaluation. Some parameters like ships width or fairway width can be obtained from UAV. It is important that the SD models are used in long – term "what if" analysis. In this case simulation results can be helpful for example in decision about fairway reconstruction.

5. Conclusions

The article presents possible scenarios of using the UAV and information obtained from it. The parameters of the drone and its construction allow for a 25-minute continuous flight with the possibility of recording video materials with a resolution of 4k. The basic possibility of using UAV in monitoring inland waterways is passive observation of the state of the river and water infrastructure. This article proposes to go further and use image processing and analysis algorithms - analogically as in road or air transport - to automatically determine the parameters of inland units traffic. To know basic data such as flight altitude, angle of inclination of the video recorder, distance from the elements of the fixed object of the environment, it is possible to obtain parameters of inland units traffic such as position, speed and distance from other objects. Those parameters can be used in system dynamic models for evaluate in long time period safety of inland fairway. Another option is to use video material for imaging augmented reality with the use of additional VR devices (helmet and manipulators). The use of virtual reality technology and the possibility of full immersion in a three-dimensional virtual world allow explore new ways to control and interact with UAV. However it is crucial to test the human view on this subject. It is unknown how a man could physically deal with those technologies. The biggest disadvantage of using the UAV for monitoring the fairway is undoubtedly the working time on one battery, amounting to about 25 minutes. During this time, we are able to verify the passage of up to two vessels. Then it is necessary to land the drone and replace the battery with a fully charged one. The test set was equipped with four batteries. This gives a total flight time of about 80 minutes, subtracting the time needed to take off and land.

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