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OVERVIEW OF THE DEVELOPMENT OF THE MARITIME SEARCH AND RESCUE SYSTEM IN CROATIA

ABSTRACT

According to the Convention for the Safety of Life at Sea and International Convention on Maritime Search and Rescue, saving human lives at sea is the duty of all signatory states. This paper analyzes and gives an overview of previous research activities in search and rescue system at sea and how the use of unmanned aerial vehicles (UAV) can improve search and rescue actions at sea. Research activities include development of the search system and placement of resources that are used in search and rescue actions (ships, planes etc.). Previous research is mainly related to minimizing response time when accidents at sea are detected in relation to search and rescue missions. Implementation of unmanned aerial vehicles into the search and rescue system enables improvement of these actions due to earlier detection and verification of accidents at sea and prevents unnecessary search and rescue units engagement in cases when an accident did not occur. The results of previous research point to the fact that future research should aim to explore the synthesis of unmanned aerial vehicles with the existing search and rescue system at sea in Croatia.

KEY WORDS

search and rescue; accidents; response time; unmanned aerial vehicle (UAV);

1. INTRODUCTION

According to national and international legislations, giving aid to people in life-threatening danger is the duty of all signatory states of the International Convention on Maritime Search and Rescue, including Croatia. Any action taken so that the danger threatening people or assets at sea is removed constitutes saving. During search and rescue (SAR) actions at sea, good coordination of all involved results in a high percentage of successful actions. The purpose of this paper is to make an analysis of previous research related to maritime SAR systems, examine the advantages

of the use of UAVs in SAR actions at sea as well as trends in future development of the subject area. It is assumed that the use of UAVs in SAR actions at sea can lead to earlier detection and verification of accidents at sea and easier detection when an accident did not occur. Until present, improving maritime SAR systems when identifying persons in distress meant increasing the number of marine rescue units (MRU), which also meant high financial costs when buying those units as well as engaging the crew that operates them that is in danger while searching the area when confirming the accident or finding persons in distress. Previous research that was related to the development of SAR systems is connected to the improvement of the search system, placement of resources and optimization of resources in correlation to weather conditions. The paper also analyses possible development suggestions in the area of SAR actions at sea with an overview of possible solutions of improvement in the search area and placement of Search Rescue Units (SRUs). Considering the fact that at a sea temperature of 4.5 °C a person can survive in water less than an hour, guidelines for SAR system development are directed to minimizing response time of SRUs. The above points to a clear need for analysis of response time as a key variable in SAR actions. A synthesis of unmanned aerial vehicle systems and SAR systems is a possible solution for SAR system improvement, which could highly improve the Croatian SAR system due to its highly indented coast. According to research [1], set-up time of a UAV is 4 minutes. The same time for MRUs that are not at sea 24/7 is much longer because it includes crew arrival and boarding and ship or aerial vehicle preparation. It can be assumed that the available technical solutions in the form of unmanned aerial vehicles are financially acceptable and enable quick and easy application in SAR actions. It is

assumed that these are the main advantages of using this technology and that it would be beneficial to both SAR and persons in distress.

2. ANALYSIS OF DUTY TO SAVE LIVES AT SEA

According to the United Nations Convention Law of the Sea (UNCLOS) of 1982, every coastal state is obligated to maintain an efficient SAR service to provide safety at sea and above sea, and to cooperate with neighbor states [2]. According to Article 123 of the Criminal Code of the Republic of Croatia, people have the duty to help others that are in direct life danger (but without major danger for themselves and others), and if they do not do so, they shall be punished with a fine or a year in prison [3]. This issue is similarly regulated in most states.

According to Regulation 10 of the Convention for the Unification of Certain Rules of Law respecting Assistance and Salvage at Sea of 1910, every captain has the duty to render assistance to every person, unless it causes danger to the ship, crew and passengers.

In accordance with Article 8 of the Convention for the Unification of Certain Rules of Law with respect to Collisions between Vessels of 1910, after collision, captains of both ships have the duty to render assistance to the other ship, its crew and passengers, for which the captain is responsible, not the ship owner.

In accordance with Article 12 of the UN Convention on the High Seas of 1958, each state requires the captain of the ship sailing under its flag, insofar as he can do so without serious danger to the ship, crew or passengers, to render assistance to every person in danger found at sea [4].

Chapter V, Regulation 10 of the International Convention for the Safety of Life at Sea (SOLAS), which regards the safety of navigation, requires the captain, when he receives the information that a ship, plane or boat is in danger, to urgently render assistance to persons in danger and, if possible, to inform authorized services about it [5]. If he is not able to do so, he has the duty to write in the ship's logbook a valid reason why he had not rendered assistance to the persons in danger.

Furthermore, the signatory states of the SAR Convention commit to develop national SAR at sea services and to provide [6]:

- necessary resources (communication, maritime and aerial searching resources and the like),
- a successfully implemented legal framework and
- planning, development and improvement of the service's work.

Possible development of the SAR system was analyzed in the research [7], where a comparative analysis was made of the applied SAR systems in eight

countries. It is evident from the research that for the development of the SAR system a good coordination of all those involved in the service is indispensable – a certain prerequisite for the development of this system.

3. OVERVIEW OF SAR AT SEA IN CROATIA

Efficiency of the system reflects the existence of services that are necessary for the functionality of the system, and they are organized and managed in accordance with international regulations. The structure of the maritime SAR service in Croatia consists of the following bodies [8]:

- SAR service headquarters,
- National Maritime Rescue Coordination Center (MRCC),
- Maritime Rescue Sub-Center (MRSC) and
- Coastal observation units (coastal radio stations, guarded lighthouses, port offices of all port authorities and observation stations of the Croatian Navy).

In accordance with the regulations of the Republic of Croatia, the same person performs the duty of the Head of the Vessel Traffic System (VTS) and the Head of the SAR Rijeka. That person is the organizer and coordinator of SAR at sea, and, if needed, coordinates it with national centers of other countries [9]. Therefore, the MRCC is his responsibility [10].

The MRSCs are located at port authorities, i.e., the Port Authorities of Pula, Rijeka, Senj, Zadar, Šibenik, Split, Ploče and Dubrovnik. The Croatian VTS is a part of the SAR Headquarters and it enables coordination during SAR actions at sea. The marine traffic surveillance system in Croatia consists of marine radar systems, Automatic Identification System (AIS), marine radio-communication system and other systems that provide insight into the situation of maritime navigation and interaction with participants. The radar system consists of ten stations placed along the coast. The application of the AIS system is prescribed for all merchant ships based on amendments to the SOLAS Convention of 2000. One of the important elements is surely the Electronic Chart Display and Information System (ECDIS) which contains integrated data from the AIS and the radar system.

The SAR service at sea includes 48 vessels of the Ministry of the Sea, Transport and Infrastructure, 38 vessels of the Ministry of the Interior and the Ministry of Defence of the Republic of Croatia. If needed, tugs and ecological units as well as privately owned planes and vessels are included [8].

Data collected for SAR actions is connected to the meteorological data, available ships' positions (collected via the Mandatory Ship Reporting System, AIS system and Long Range Identification and Tracking of Ships systems) and available SRUs. According to the research in [11], data is continuously updated with

respect to the development of the situation related to the incident that conditioned that action. Decisions are made depending on the current SAR situation with detailed instructions for the On-Scene Coordinator (OSC) responsible for the SAR coordination. In addition, instructions are given to their own ships and planes, ships and planes that belong to collaborative institutions and other available ships and planes. The search starts immediately after receiving confirmed information about the person, ship or plane that is in danger. If a merchant ship passes near the accident site, it goes to rescue if needed, in which case contact is made with the MRCC, MRSC or some other ship with which important data is synchronized.

4. OVERVIEW OF PREVIOUS RESEARCH ON MARITIME SAR SYSTEMS

4.1 Search system development

The first mathematical models used for search at sea were based on the search theory that was developed during the Second World War, and it was used mainly when searching for survivors in military operations. Due to greater search efficiency, more mathematical models were developed that enabled better search results. The basic goal is to find the missing person/ship in as little time as possible. One of the most widely used models in search actions was developed by Koopman, and it is the so-called random search formula [12]. It can be shown using the following description:

$$POD = 1 - e^{-c} \quad (1)$$

where POD is the probability of detection, e is the natural logarithm base and c is the coverage path.

During the search, it is necessary to define a possible search area ('data') that can represent a point, line or an entire area defined based on the position and time of the last reporting considering the weather conditions. The data position is different from the real position of the object or person at the moment of the received call for help because the data position needs to be corrected according to its leeway due to variable weather conditions in the field, which is shown in *Figure 1*. The value R is the initial error concerning the last known position.

When the position of the data is received, the search can begin. If the search is performed using ships, then expanded square search is used as well as sector search. If two or more ships participate in the search, then parallel sweep search is used [13]. In combined searches it is very important to coordinate search speeds of the ship and the plane. The ship's speed can be calculated using the following formula:

$$V_s = \frac{SVa}{L+S} \quad (2)$$

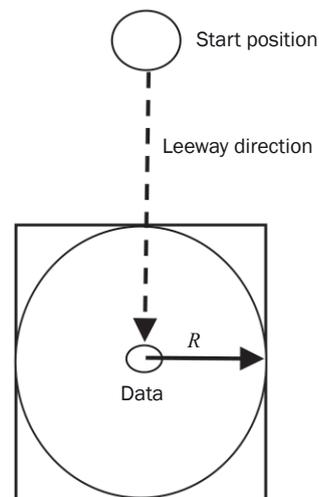


Figure 1 – Determining the data position at the beginning of search [13]

where V_s is the ship's speed in knots, S is the distance between paths in nautical miles, Va is the plane's real speed in knots and L is the length of the path's side of the plane search in nautical miles.

Further research that was based on determining the possible position of the data using sophisticated computer models was first implemented by the United States Coast Guard [14]. Most of the research that followed focused on the problem of object's leeway based on weather conditions. Every SAR operation's goal is to increase the probability of success – POS , which is dependent on the previously mentioned POD and the probability of containment – POC [15].

$$POS = POD \cdot POC \quad (3)$$

Further development that regards leeway direction was analyzed in [16], while in [17] the OCEAN-SAR decision support system was defined. The system is based on the leeway model and it uses wind condition and weather forecast as input data [18]. If it is known where and when the accident happened, it is possible to display the area where the person or the ship might currently be considering the weather conditions that occurred in the meantime. However, the longer the time period from the start of the search, the larger the search area. So, the challenge in future research is the increase of the data's space dispersion with the increase of time due to leeway.

4.2 Previous research regarding the placement of SAR resources

An operative service at sea consists of rescue resources that comprise each land, marine or air unit (including all equipment, personnel and communication devices) used in SAR actions or responding to a call for help. It consists of marine and air rescue units. Marine

rescue units consist of rescue vessels (RVs), rescue boats (RBs), fast rescue boats and other all-purpose ships (warships, pilots, coastal tugs, merchant ships that were on the spot and others). Air rescue units (ARUs) consist of planes and helicopters.

In order to perform a successful SAR action, it is important to establish good coordination between MRCC, MRSC, MRU, coastal observation units and other involved in search and rescue actions.

Strategic planning of the placement of SAR resources regards as much as sea area coverage as possible with as little SAR resources as possible. Due to the specific nature of SAR areas at sea, it is necessary to take into consideration multiple factors when modeling the coverage grid of the sea area with SAR resources [19]:

- characteristics of the accident, vessels and damage incurred,
- accident type and severity,
- placement of resources (MRUs) and
- placement of resources that show the location suitability indicator and cost effectiveness.

Area coverage can be taken as a zone coverage considering that the resources are placed in the MRSC or other coastal stations. So, according to [19], the resource zone allocation coefficient R was defined, which relates to each individual rescue units in the coverage zone, i.e.:

$$ZA(R_r, P_p) = S_{P_p, R_r} \sum_{z=1}^{z=n} \left[\frac{W_z}{d_{z, P_p}} \right] \quad (4)$$

$\forall z \in \text{Radius of action of } R_r$

where $ZA(R_r, P_p)$ is the zonal assignment coefficient of rescue resource R_r located in the specific placement P_p , R_r is the means of rescue or resource to locate ($r=1,2,\dots,m$), P_p is the placement evaluated ($p=1,2,\dots,k$), S_{P_p, R_r} is the suitability factor of placement P_p for resource R_r , z is the zone within the radius of the action of the rescue resource R_r located at P_p ; $W_z(t)$ is the weight of 'superaccident' (represents the arithmetic mean of locations of all accidents in a certain zone) of zone z in the period t . d_{z, P_p} is the distance between the placements evaluated for resource P_p and the 'superaccident' of zone z . One flaw of the mentioned model is the fact that it does not take into consideration traffic infrastructure and available work support that would have a big role in it. Also, SAR signatory states, including the Republic of Croatia, have the duty, when implementing SAR plans, to make cooperation agreements between institutions as well as between states. Croatia arranged this in a way that when resources are placed, if needed, it can use other cooperative agencies' resources (Croatian Navy etc.).

Interesting research was made in [20] about possible locations of SRUs in the area of Canada's east coast. The goal was to reduce total response time and to balance load. The goal function was to cover

as many incidents as possible in as little time as possible using a previously defined number of units. The challenge was the fact that the Canadian Coast Guard owns SRUs with different characteristics (speed, total reach, special equipment etc.). The resource placement problem in area search can be reduced to the maximal covering location problem (MCLP) which can mathematically be shown as follows [21]:

$$\text{Max } z = \sum_{i \in I} a_i y_i \quad (5)$$

$$\text{s.t. } \sum_{j \in N_i} x_j \geq y_i \quad \forall i \in I \quad (6)$$

$$\sum_{j \in J} x_j = p \quad (7)$$

$$x_j \in \{0,1\} \quad \forall j \in J \quad (8)$$

$$y_j \in \{0,1\} \quad \forall i \in I \quad (9)$$

where I denotes the set of demand nodes (incidents), J denotes the set of candidate location sites for facilities as supplied by the CCG, a_j is the demand in each demand zone (e.g. grid) i , $x_i - 1$ if a facility is allocated to the site j , S is the specified maximum response distance for the reaction of SRUs, $N_i = \{j \in J | d_{ij} \leq S\}$ - the cover set for each demand zone i within the desired response distance S of a facility site j for the reaction of SRUs, p - the number of facilities to be located.

The research divided incidents into four types: M1 - distress incident, M2 - potential distress, M3 - non-distress incident and M4 - false alarm which denotes that the ship was informed on its way to the incident that it was a false alarm and was directed to return. Concerning the aforementioned, only incidents M1, M2 and M3 are included in the research, from which follows: [21]

$$\text{Max } z = \sum_{i \in I_1} a_{1i} y_{1i} + \sum_{i \in I_2} a_{2i} y_{2i} + \sum_{i \in I_3} a_{3i} y_{3i} + \quad (10)$$

with the condition that:

$$\sum_{i \in I_1} a_{1i} y_{1i} \geq r_1 T_1 \quad (11)$$

$$\sum_{i \in I_2} a_{2i} y_{2i} \geq r_2 T_2 \quad (12)$$

$$\sum_{i \in I_3} a_{3i} y_{3i} \geq r_3 T_3 \quad (13)$$

where r_1 , r_2 and r_3 represent the minimal number of incidents M1, M2 and M3 which have to be covered, while T_1 , T_2 and T_3 are related to the total number of incident types M1, M2 and M3. The question arises what to do with the alarm type M4, which is not included in calculations in this research. It is suggested to introduce the new element M4 in future research because it involves occupied SRUs until the report about the false alarm has been received. M4 was up to 12,71% in the presented research.

4.3 Development in the area of SAR resources optimization related to weather conditions

To define the level of efficiency of the applied SAR system, it is necessary to define types of rescue units in the system as well as their spatial placement and response time. The level of efficiency can be defined as the level of response time to a sudden distress situation. When response time of all types of ships is in question, it is directly influenced by the current state of weather which is related to the state of wind and sea. In ideal weather conditions, response time and autonomy is defined by the characteristics of the vessel itself. However, response time in adverse weather conditions depends on strength/direction of waves and wind. Furthermore, conditions such as haze and rain can also affect performances of SRUs. According to the research made in [22], coverage path for Finland coast was defined taking into consideration the amount of available units that were divided into groups of vessels depending on the length. The research also defined response time of all vessels based on their maximum speed and weather conditions (wind and waves). A raster map was used instead of a vector map to easily calculate the cost of the path in the calculation model (which in the research denotes response time). The problem was that due to the way those maps are made, not all sea areas were covered all the time.

5. MARITIME SAR DEVELOPMENT GUIDELINES

5.1 New technologies in the SAR system

In SAR actions at sea, a problem of slowness of area coverage (due to time needed to activate the entire SAR system mentioned in the introduction) is encountered as well as of reduced search efficiency when using ships and aircraft. If there is a need to search a sea area that encompasses the northern side of Šolta and Brač islands under severe weather conditions, the search would last for many hours if all the available ships were to be included in SAR action in Split-Dalmatia County. There is a need to introduce a component that would be able to search the mentioned area in a much shorter period of time, for example up to an hour. One of the possible solutions is the use of UAVs, which use new technologies and are able to cover much larger areas and therefore increase the success of SAR actions.

5.2 UAV system analysis

The term UAV denotes an aircraft without any crew. The military initially started developing UAVs with the goal of minimizing human victims and maintenance costs. The architecture of the UAV system is shown in

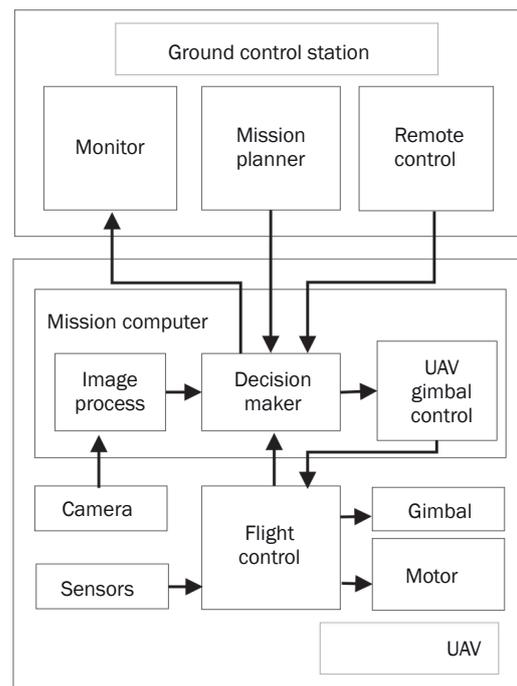


Figure 2 – Basic structure of the UAV's hardware system [23]

Figure 2 and consists of a ground station that includes a monitor, mission planner, remote control and the UAV itself, which consists of an image processor, a part which is related to the decision support, image stabilizer control, camera, sensor, flight control and motor [23]. The navigator always has control over the UAV, based on constant connection (via radio or satellite). The complexity of the control station depends on the size of the UAV as well as on sensors and cameras connected to it. They can have one or more operators, and one of them controls the UAV while the other manages the program control which analyzes the data collected by the UAVs in real time. Sensors that are used during the area search are a multispectral sensor, thermal sensors, infrared sensors (IR) and hyperspectral sensors. Using some of these sensors which are integrated into certain types of UAVs, it is possible to analyze images and/or videos and detect the person, persons or objects that are being searched for. Certain applications in practice have proven to be successful and as such are applicable in the maritime SAR field.

There are two options for controlling UAVs: remotely or independently according to the previously determined flight plan. If a UAV has been launched and is searching according to previously known positions (the aforementioned includes remote control), it has to be in constant contact with the control station. If the contact is lost, the UAV is ordered to immediately start the navigation towards the position from which it launched. This algorithm is shown in Figure 3.

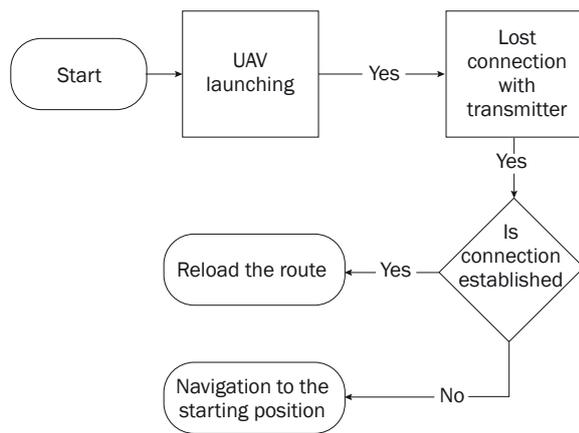


Figure 3 – Decision algorithm in case of signal loss between the UAV and the control station

5.3 Progress in UAV system use

With the development of technology, UAVs has been on the rise even for civilian purposes. Their use in technical inspection of infrastructure is significant [24, 25], as well as in navigation according to defined points which include area mapping [26], obstacle avoidance [27], real-time environment surveillance [28] and SAR actions [29, 30]. Research related to the use of UAVs in SAR actions has been done to minimize the time of detection and rescue of a potential victim. The fact is that every delay of detection increases the chances for distress. However, in every SAR action the safety of the team involved is extremely important. Until recently, widening the search area implied another SRU together with the appertaining team. This results in additional costs for the SRU and additional risk to the team starting the search. An example of a possible solution was given in [31], where a UAV (equipped with an infrared camera) assisted the US Coast Guard in SAR actions flying in formation with helicopter-type SRUs. The new SRU was a UAV, which does not require an additional team in danger in the field. Also, this increased the width of the track during the search while reducing the search cost. The ICARUS project confirmed the functionality of UAVs in SAR actions [32]. Namely, the project researched the application of robotics in disaster/SAR actions where land, air and marine autonomous vehicles were developed and demonstrated. The goal was to achieve the heterogeneity of robots and missions and make robots that are suitable for varying missions, which would reduce the total cost of the accident (natural disaster, SAR actions etc.). The tests successfully demonstrated the experiment of detection and saving a victim at sea using UAVs (equipped with optical and thermal cameras) and crewless vessels. In the framework of the Deployable SAR Integrated Chain with Unmanned

Systems (DARIUS) project, it was researched how to introduce a UAV system in a maritime and land SAR system [33]. This was achieved by designing a ground control station (GCS), which ensured the command and control of multiple UAVs at the same time. However, the project solution was not efficient due to high costs and procedural reasons. It can be concluded that better results could be obtained by using the available UAV solutions together with the applied control functions of MRCC. Moreover, UAVs could be used for coastal and offshore SAR actions. Considering the fact that the Croatian part of the Adriatic is highly indented (it has 1185 islands), improvement to the maritime SAR system using UAVs represents a good solution. Even the current development trend of battery-powered UAVs that enable 30-minute flights encourages their use in coastal SAR actions.

5.4 Analysis of response time as the key variable

To further SAR system efficiency, future research needs to be directed towards accident response time reduction and cost analysis of the use of available resources. According to [34], the following elements can influence response time:

- Detection of incidents and time verification (T_1) represents the time between the time the accident had really happened and the time when it was detected and confirmed by the MRCC,
- Rescue team deployment time (T_2) is the time between identifying the location, type and severity of the incident and sending the first available rescue team and
- Rescue team travel time to incident site (T_3) is the time which is necessary for the rescue team to reach the location of the incident.

If any of the presented three components can be affected, total response time will be reduced.

The influence of using new technologies (UAVs) on time needs to be researched. With the right placement of the UAV system in the coastal area, its SAR system can act almost immediately, obtaining an actual image of the possible accident and activating appropriate resources depending on incident type. Application of this system would directly affect M4 type of incidents which would reduce false alarms to a minimum.

SRU deployment in SAR missions can cause major costs and occupation of MRCC resources. The question arises what to do when a new distress situation occurs while all SRUs are occupied with another action. Introducing the UAVs into the (MRCC) SAR system would result in an almost immediate area coverage, so that SRUs are not sent when there is no need. In addition, equipping each marine SRU with a UAV would reduce area search times.

6. CONCLUSION

The basic goal of the SAR system research is to improve the existing system to make the response time to an accident as short as possible and to get the information about the actual state of the ship/person in distress. Although the OCEAN-SAR project gives possible accident locations with great precision, the search area increases as the information about the possible data arrives late, therefore reducing *POS* as well. The goal is to get the information about the data in as little time as possible. Future research should focus on improving the usability of OCEAN-SAR so as to obtain the information about the data in a shorter period of time.

Another problem is related to the placement of resources and response time during distress. Introducing new resources into the SAR system (such as UAVs) influences zone coverage. It can be concluded that it is much easier to add a UAV as a new searching resource than a ship or a plane/helicopter. Previous research about possible locations of SRUs with the goal of reducing response time did not include false alarm reports.

Due to rapid development in the field of UAVs, use of existing technical solutions with optical camera (preferably thermal camera as well) is suggested for the improvement of the SAR system. If the UAV system is introduced into the existing SAR system in the Republic of Croatia, this will influence M4 type incidents that will be significantly reduced, and it will enable earlier detection and verification of accidents at sea. Future research should look for answers to challenges regarding the introduction of UAVs in the SAR system; questions such as which technical solutions of UAVs should be used, who will have control over UAVs, spatial placement of UAVs, and ways to ensure compatibility with the existing SAR system.

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PREGLED RAZVOJA SUSTAVA TRAGANJA I SPAŠAVANJA NA MORU U HRVATSKOJ

SAŽETAK

Prema Konvenciji o zaštiti ljudskih života na moru (eng. *Convention for the Safety of Life at Sea*) i Konvenciji o traganju i spašavanju na moru (eng. *Search and Rescue Convention*), spašavanje ljudskih života na moru obaveza je svih država potpisnica. U radu je provedena analiza i predstavljan pregled prethodnih istraživanja u vezano za sustav traganja

i spašavanja na moru i kako korištenje bespilotnih letjelica (eng. *Unmanned Aerial Vehicles - UAV*) može unaprijediti akcije traganja i spašavanja na moru. Istraživanja uključuju razvoj sustava traganja i raspodjelu resursa koji se koriste u akcijama traganja i spašavanja (brodovi, zrakoplovi, itd.). Prethodna istraživanja uglavnom se odnose na smanjenje vremena odaziva na nezgodu na moru, nakon čega slijedi misija traganja i spašavanja. Implementacija bespilotnih letjelica u sustav traganja i spašavanja omogućuje unaprijeđenje tih akcija u vidu ranije detekcije i verifikacije nezgoda na moru i sprječava nepotrebnu zauzetost jedinica za traganje i spašavanje u slučajevima kada se nezgoda nije dogodila. Rezultati dosadašnjih istraživanja upućuju na činjenicu da bi se daljnja istraživanja trebala usmjeriti prema istraživanju sinteze sustava bespilotnih letjelica s postojećim sustavom traganja i spašavanja na moru u Hrvatskoj.

KLJUČNE RIJEČI

traganje i spašavanje; nezgode; vrijeme odaziva; bespilotne letjelice;

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