Personal warning system for vessels under bad weather conditions

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ABSTRACT

Many services provide weather forecasts, including severe weather alerts for the marine. It proves that many ships neglect the warnings because they expect to be able to handle the bad weather conditions. In order to identify possible unsafe situations the Coast Guard needs to observe marine vessel traffic 24 hours, 7 days a week. In this paper we propose a system that is able to support the Coast Guard. Ships can be localized and tracked individually using the Automatic Identification System (AIS). We present a system which is able to send a personal alert to ships expected to be in danger now or the near future. Ships will be monitored in the dangerous hours and routed to safe areas in the shortest time. The system is based on AIS data, probabilistic reasoning and expertise from the Coast Guard. A first prototype will be presented for open waters around the Netherlands.

Keywords

Early warning systems, personal context sensitive alerts, maritime surveillance, Automatic Identification System, Bayesian reasoning.

INTRODUCTION

The Netherlands is surrounded by many open waters, the North Sea, Waddenzee and the Ijsselmeer. Along the coast there are many harbors for recreational sailing and small motor boats. On a sunny day many people take the opportunity to sail in open water. But the weather conditions can change very quickly and a sailing vessel needs some time to reach a safe harbor, depending of its current location, the direction of the wind and water, power of the engine and sailing experience of the crew. If bad weather is to be expected a general alert is generated by the Weather Forecast Service. But in many cases this alert will be neglected because the sailing trip is planned, people believe they are in a safe area, the weather will not change so dramatically as predicted, there is enough time to reach safe harbors or they believe the boat and its crew is adapted to bad weather condition. But it happens many times that boats get into troubles and the Coast Guard has to provide assistance (Coast Guard, 2012).

In this paper we propose a personalized, context sensitive early warning system, which is part of an automated surveillance system for open waters, taking care of the safety of vessels, especially recreational sailing boats which is a group at risk. Currently there is a lot of interest in designing personalized early warning systems in the community of researchers involved in crisis management and information systems (Fraunhofer,Fokus, 2013; Opti-alert, 2013; Mossgraber et al., 2013; Rothkrantz, 2014).

At this moment most ships have communication systems, radar systems and Automatic Identification (AIS) on board. The AIS is an automatic tracking system used on ships and by Vessel Traffic Service (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites. When satellites are used to detect AIS signatures then the term Satellite-AIS (S-AIS) is used. AIS information supplements marine radar, which continues to be the primary method of collision avoidance for water transport. Unfortunately there is no legal requirement for sailing boats to have an AIS system or transponder on board, but fortunately most ships sailing on open water, at night with limited vision condition have an AIS system for their own safety. But all these equipment, including many commercial systems give

only data about other ships. The crew has to take decisions about evacuative actions. Large ships usually sail at a much higher speed than sailing boats and cannot turn or stop easily. Every year some collisions happen based on miscalculation of the risk of traversing a Traffic Separation Scheme by the crew of sailing boats. The crew has also to decide about appropriate actions in case of bad weather conditions. But according to the yearly report of the Coast Guard many miscalculation of the risk take place. Our proposed system provides a personal, context sensitive risk calculation and in case generates a personal alert, which is needed especially under bad weather conditions.

Many commercial safety and security systems have been developed for the oil and gas industry. To protect this critical infrastructure surveillance systems have been developed including integration of multiple sensor systems such as AIS and Radar, weather sensors to compute the risks of changing weather and sea conditions. The development of surveillance systems for sailing boats has a low priority. In order to identify possible unsafe situations the Coast Guard has to observe marine vessel traffic 24 hours a day, 7 days a week. Monitoring marine vessel traffic is a labor intensive job. In this paper we propose a system that is able to replace or support traffic controllers with their monitoring task. The system aims to emulate the reasoning process of human operators. Towards that goal we have developed Bayesian- reasoning models based on operator knowledge. Besides these models the system employs statistically derived information about shipping movement from sources as Automatic Identification System (AIS). Using the combination of modeled and learned knowledge, the system is able to determine the probability of dangerous situations.

Figure 1. Control room of the Coast Guard   **Figure 2. Example display AIS data around the Netherlands**

The AIS data is displayed on the computer screens of the operators (see Figure 1, 2). They have to monitor the track of all vessels in parallel and to detect ships in danger. It is impossible to send rescue vessels to all ships in danger. So the challenge of our research is to design an automated personal early warning system. Such a system has to satisfy the following requirements:

- The system is able to localize and track ships using AIS and to predict the expected route. Then the possible risk has to be computed for individual vessels taking care of the changing water and weather conditions, historical data and static (category of ship, engine) and dynamic parameters of the ship (position, heading and speed).

- The system is able to send a personal alert to the ships to be expected in danger now or the near future. It is expected that a personal alert has a greater impact than a general anonymous alert. The crew of the ships becomes aware of the fact that the Coast Guard is monitoring them.

- The system is able to monitor ships in danger and analyze the track to see if the ships show appropriate to be expected behavior.

- The system is able to provide additional routing information. In case a ship takes a shortcut to save time, the ship can sail in unknown, shallow water, with unexpected strong water streams.

- Ships in the neighborhood of a ship in danger can be alerted to provide assistance if needed.

- A ship in stress can send a NUC (Nursing and Care) message, which will be processed with highest priority by the system (if all systems fail on board, a radio beacon is able to transmit an SOS alert continuously).

The outline of the paper is as follows. In the next section we provide an overview of surveillance systems. Then we present the architecture of our system and implemented modules. Then we present some test examples and end up with a conclusion and references.

RELATED WORK

Surveilance systems

On the technical aspects of monitoring ship traffic, the European Commission outlined a policy on maritime surveillance information systems (European Commission, 2008). The report summarizes information on existing maritime surveillance systems and focuses on data sharing aspects at a European level. It also discusses the strengths and weaknesses of systems in operation and the report identifies challenges that are to be expected when integrating these systems. Most importantly, the report acknowledges that maritime situation awareness can be and should be improved. Building on this report, the European Maritime Safety Agency (EMSA) initiative "Safe- SeaNet" aims to create a centralized European platform for maritime data exchange, linking together maritime authorities from across Europe (European Maritime Safety Agency, 2013). It enables European Union member states, Norway, and Iceland, to provide and receive information on ships, ship movements, and hazardous cargoes. Main sources of information include Automatic Identification System (AIS) based position reports, and notification messages sent by designated authorities in participating countries. As the aforementioned EU report indicates, rich data about vessel movement at sea has become widely available with the development of systems such as AIS (AIS, 2013). AIS has opened up many possibilities to enhance monitoring capabilities at real time. It can be used to detect and prevent possible collision between two vessels. The idea that aggregated AIS data is useful for analyzing (behavioral) patterns in marine vessel traffic, as put forward in this paper, is not new, and used in many Coast Guard operator rooms for monitoring professional vessels. But to use AIS data for an automated surveillance system of recreational sailing boats is innovative. Needless to say is that many government agencies, such as the coastguard, customs, intelligence service and the navy, are very interested in the trends that could be derived from AIS big data.

Personalized warning systems

In November 2013 an International Conference was organized on public alerting and social media during crisis and disasters (Fraunhofer Fokus, 2013). The conference had the following sessions relevant for this paper: Alerting Methods and Techniques: Current State (session 1), Multi-Channel Approach in Public Alerting (session 2), Case Studies for Public Alerting (session 3), Integration of Public Alerting and Social Media (session 8). This shows that public alerting systems is a research topic nowadays. Many speakers call for new ways of public alerting systems. The current paper is supposed to contribute to that goal.

OPTI-alert (OPTI-alert, 2013) is a research program funded under the European 7th Framework Programme. On the website of the project is stated that the aim of the program is enhancing the efficiency of alerting systems through personalized, cultural sensitive and adaptive multichannel communication. As deliverable the project will create an adaptive alerting system that allows intuitive, ad-hoc adaptation of alerting strategies to specific alerting contexts. In recent years, public authorities and private companies have invested heavily in different types of alerting systems. Examples include the WIND storm warning system, financed by the insurance industry; the publicly funded German-Indonesian Tsunami Early Warning System (GITEWS); the HAZARDOUS flash flood warning system in Italy; and the more general-purpose Emergency Alert System (EAS) in the United States (OPTI-alert, 2013). These alerting systems now allow users to subscribe to different types of alerts and to select alert levels and communication channels. However, the composition and design of alert messages currently depends only on the user's functional role: There are specific messages for members of the emergency services, homeowners, motorists etc. The personal, cultural and social characteristics of the warning recipient are not taken into account in message composition and delivery. This shortcoming is significant in case of large-scale international disasters such as tsunamis, storm surges, large-scale nuclear accidents and hurricanes, which require an integrated, multi-national warning and alerting strategy for the general public. Due to the lack of cultural and personal sensitivity of existing alerting systems, warning messages are currently not ideally adapted to the recipients, and therefore cannot achieve optimal impact. The first scientific results are described by (Klafft et al. 2008). Our paper is in line with this new research initiative.

In the framework of the EU FP7 project TRIDEC (Mossgraber et al., 2013) defined a system architecture for a Tsunami early warning system. They used a system-of-systems approach to integrate various components and subsystems such as different information sources, services and simulation systems. Furthermore, it has to take into account the distributed and collaborative nature of warning systems. There are similarities with our early warning system. But in this paper we focus on the alert messages and less on the technical aspects.

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THEORETICAL BACKGROUND

In the report "Global Survey of Early Warning Systems (United Nations, 2006), an overview is presented of comprehensive global early warning system for all natural hazards and an assessment of capacities, gaps and opportunities toward building. This Report was prepared at the request of the Secretary-General of the United. Nations, UN/ISDR. In this report is stated that messages should be understood, verified and personalized. According to Jagtman (Jagtman, 2010) messages must be send properly, messages have to be received and messages must be read and the recipient has to carry out the action required in this message. All these requirements look evident but the implementation is far from trivial as we will show in our developed prototype. On the International Conference on Public Alerting and Social Media during Crises and Disasters, many authors report about requirements for early warning systems and present recent applications (Fraunhofer Fokus, 2013). In his paper, Klafft (KLafft, 2013) reports about multichannel communication in early warning systems. He reports about a lot of research that has been conducted to analyze the first steps of the alerting process, i.e. sending and receiving alert messages. These studies have mainly followed three different approaches:

1. Analysis of statistics for different media, such as the technical coverage, the availability of the medium among the population, and usage statistics.

2. A second approach uses dissemination simulation models to obtain insights into emergency alert propagation.

3. A third approach analyses the perception of alert messages by collecting user feedback after test alerts.

By the huge grow of social media a new generation of alerting systems is popping up. Social media, self-organization, autonomous behavior, personalization, context sensitive, and adaptation are important keywords. The numerous theoretical and prototypical approaches to these challenges still have to prove their value in everyday applications. The current paper is supposed to contribute to that goal.
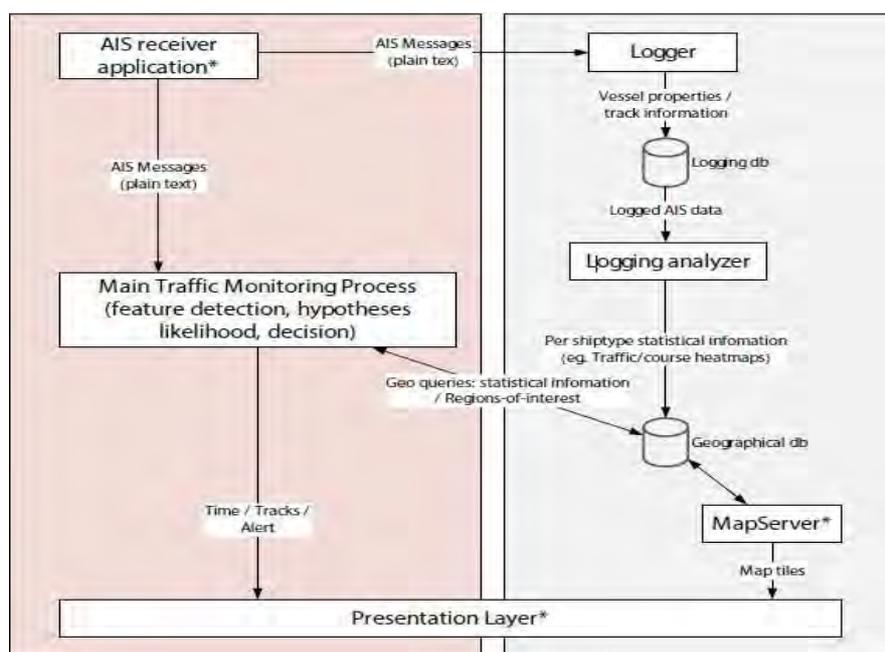
ARCHITECTURE

Figure 3. Architecture of the system

Building a prototype of a marine vessel personalized warning system means the proposed concepts must be translated to a software design and then implemented in the said prototype. An overview of this prototype is shown in Figure 3. The individual components can be separated in two groups: A (near) real time processing part and an offline data acquisition and analysis part. This section will discuss the particulars of the processing chain of the monitoring system. It contains a number of sub processes that are triggered sequentially. *The AIS receiver* gets AIS messages. These messages are binary according to the National Marine Electronics Association (NMEA) 0183 standard. Once the messages are decoded, they can be retransmitted to the main monitoring application or saved to disk as a log file. The main monitoring application functions as the central information repository of the system. It keeps track of time, vessels and their tracks and contains a (limited)

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track history. Using the information available in this component, the system reasoning routines can determine the measure of risk for a vessel. In *Data Acquisition and analysis* component the processes take place to build the database that contains historical information about marine vessel traffic. The logging will be discussed in the next section *Data Logging*. The logging analyzes the historical data in order to establish information that describes normal behavior, such as shipping densities and mean courses at certain latitudes/longitudes. From the processed loggings, maps can be made that denoted the shipping density, median course and median speed at a certain point on the map for a certain group of ship classes. This is done by rasterizing the track data to a predetermined grid and then adding it's characteristics to the count for each cell. The different components of the architecture will be discussed in more detail.

Data logging

To acquire the relevant knowledge we decided to log the shipping behavior around the port of Den Helder. Using an Automatic Identification System (AIS) receiver, Very High Frequency (VHF) antenna, a laptop and a 60 meter high tower (Scholte, 2013), we were able to gather a substantial set of AIS data over a long period during the month April and during the weekends of bad weather forecast. Using these AIS messages, we are able to construct a picture of what features are common occurrences at the cells of the grid we are observing.
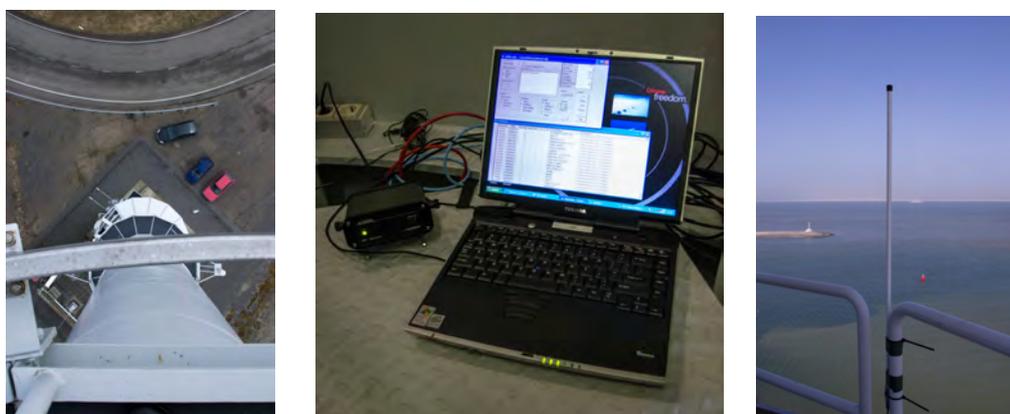

Figure 5. A high tower, laptop to log data and VHF antenna

In total 17896028 messages were logged during the observation period. An AIS receiver produces National Marine Electronics Assocation (NMEA)-0183 binary messages. This means that the incoming messages (plain text AIS messages) must be decoded to manage the data. The next step is to prune the data and store the remaining tracks. The tracks of these vessels are used to calculate the historical information, such as shipping density and median course and speed maps. All tracks were rasterized by a special designed algorithm. A cell size of 10m x 10m was selected for the reference grid. The reference grid itself, is defined as a box from a latitude of 51.5N to 54.5N and a longitude of 3.0E to 6.0E. The tracks were dilated using circle shape with a radius of 3 cells (or 30 meters given the cells size of 10 meters) to account for positional inaccuracies. Because this grid is very large, approximately 33336x33336 cells, processing this area was done in 36 tiles, each measuring 0.5 x 0.5 arc minute. The data is converted to rasterized information using special Algorithms designed in Matlab and subsequently transformed to GeoTIFF files using another Algorithm (Scholte, 2013) These files are merged afterwards. This process took about 4 days using a higher end home PC equipped with 12 Gb of RAM and Intel Core i7 930 processor.

Map annotations

There are no predefined highways on open sea, but it proves from our loggings that ships take regular routes in some areas (see Figure 6, 7). It proves that ships take different routes depending of low or high tie and wind direction etc., From that data with help of navigation experts of the Royal Navy we were able to design safe routes for different kind of vessels and different context. This enables our system also to check if a ship takes an unusual or even forbidden route. Of special interest were the short cut routes taken by vessels in danger. As was pointed out already these routes have to be detected because they can end in shallow water and deadlocks.

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Open water is a very dynamic environment. Water is coming and going with different intensity. Low and high tie is one of the main causes of the dynamic of the water streams. But in case of upcoming storms the direction and intensity of water streams differs a lot. Large ships with professionals on board usually know how to handle the changing conditions. For them a general weather alert is sufficient. But recreational sailors will be confronted with a new dangerous situation. To handle the strong water streams in the deep part of the open water and opposite wind could be far beyond their capacity. Maybe the engine on board doesn't have the necessary capacity to sail stream upwards. With help of navigation experts of the Royal Dutch Navy, Sea maps were annotated in a dynamic way dependent of time of the day, season and weather conditions. Similar to the concept "tunnel in the sky" (Barrows, 1997) safe corridors are annotated on the map. These sheltered routes guide recreational sailors to reach a safe area or harbor. Maps were annotated for the different contexts. Areas on the map were colored in red, yellow and green for the dangerous, unstable and safe areas.

Personal data

From the very moment a recreational sailing boat is leaving the harbor it will be tracked and some dynamic parameters of the boat will be assessed, such as the power of the engine, average speed etc. Static parameters such as length of the boat, seaworthiness of seagoing vessels will be looked up in a database instead of questioning the sailors. These parameters are needed to assess the risk of these vessels under heavy conditions. With help of experts of the Coast Guard safe and sheltered routes were designed. To conclude a lot of effort and knowledge of experts was used to annotate the sea maps in a dynamic way, that is to say dependent of location, time, weather, vessel parameters.
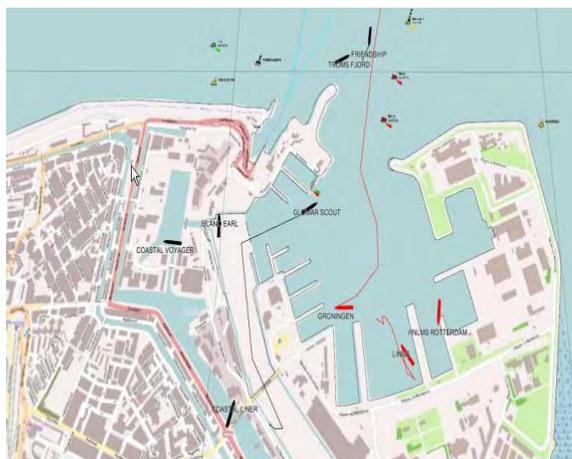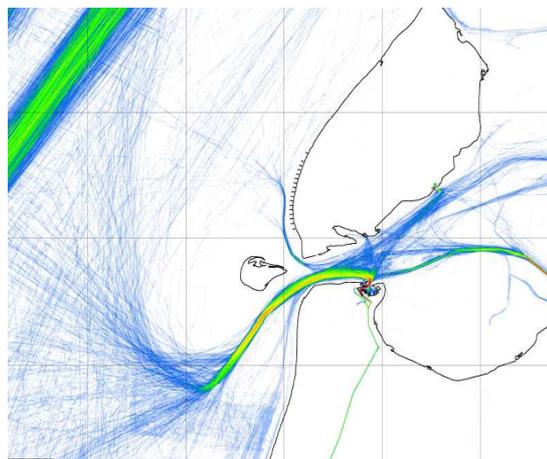

Figure 6. Map of the harbor of Den Helder

Figure 7. Map with ship routes

KNOWLEDGE MODELING

The information processing model assumes a recurring cycle of receiving data, feature detection, determining the likelihood of hypothesis and decision/act processes. The incoming data is put in a track buffer. From the data points in the track buffer, features are derived. In this study, we assume Automatic Identification System (AIS) messages, but the principles can also be applied to other data sources as long as they supply the required information. These features are used for determining the likelihood that a vessel is in danger or will be in danger near future. We restrict ourselves to recreational sailors. From professionals and large vessels can be expected that they have the expertise to handle bad weather forecast in an adequate way. For big vessels it is safer to choose for the open sea instead of shallow waters between the islands or close to the coast. But many recreational sailing boats are not designed for bad weather on open sea and have to find safe rescues.

Our system is supposed to detect whether a boat is in danger or will be in danger near future. We got our inspiration from the experts of the Coast Guard. In the control room (see Figure 1) operators are monitoring the computer screens where the tracks of boats are displayed. Some situations are considered as critical. These situations are considered as hypothesis. These hypotheses are triggered by the tracks of the boats. Every hypothesis will be verified by new data in on the next time steps or rejected. In case a boat enters a risk area it will stay in that area or makes a U-turn to leave that dangerous area. This can be concluded by continuous observation of the tracks of the boats. Via interviews and thinking aloud procedure we were able to make the

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knowledge of the operators explicit. It proves that the following situations are risk critical:

1. **Risk area:** From the position of a boat on the annotated map can be decided if the boat is already in or moving to an area of high to low risk.

2. **Moving to risk area**: From the recent track can be decided if the ship is moving in or to an area of low or high risk.

3. **Crossing TSS:** From the recent track can be concluded, if a ship is planning to cross a Traffic Separation Schema (routing highway for professional ships). There is a danger of collision. Professional vessels usually have a higher speed and are not able or willing to reduce their speed or heading. Recreational sailors have to give priority to professionals but based on a wrong or to optimistic risk calculation they may plan a too risky route. From the current positions of ships and vessels and personal/historic data can the risk probability of a collision computed.

4. **Unable to return home:** It may happen that a ship is unable to sail upwards the stream and is drifting away to open sea, or makes low progress. One of the reasons could be mechanical problems, low motor power or insufficient petrol. From the current position a safe route can be designed and observed that the ship doesn't take this route or is unable to take this route using data from personal/historic database.

5. **SOS alert:** A ship in danger can send an SOS alert and request for help. From the position of neighboring ships can be decided if they are able and willing to provide help or the Coast Guard has to start a rescue operation.

If one of the situations as defined above is detected and verified, a personal message can be send to the boat to move to a safe area. The boat will be tracked and its track will analyzed automatically. If the heading of the ship is not in the direction of a safe area, or if the ship reduces speed or even switched off the AIS system it is assumed that the vessel didn't receive the message or neglected the message on purpose. At the end every vessel is responsible for its behavior but the Coast Guard is not amused if help is requested at the very last moment. We defined behavioral actions in line with the warning messages and call the behavioral actions not in line with the warning message suspicious.

BAYESIAN REASONING

In Figure 8 we show the general reasoning process of our system. If a new ship enters the area, the following data are logged: (1) identity of the ship, (2) position and (3) time. AIS data are updated with a sample rate of 2-10 seconds. From the discrete tracks we computed the following parameters over a selected time interval: (4) speed, (5) acceleration, (6) curvature of the track and (7) heading. Then we detect change of speed and heading. We used some threshold value to take care of stochastic errors in the data. The 7 parameters are attached as a vector to the ship along its track. From the 7 parameters the system computes the probability that a boat is in one of the risky situations (hypothesis). The last step is the computation of the alert.

In a first approach we used a rule based system. If a boat is in a risk area an alert can be generated. One of the disadvantages of using a rule based system is that IF-THEN rules are always deterministic. Either the IF-condition of the rule is fulfilled or it is not. But our data are highly probabilistic. The weather forecast has some probability to be true. A boat heading a risk area has some probability to enter that area. A rule based system doesn't satisfy the requirements and a more flexible model is needed. This flexibility can be achieved using a probabilistic model. Basically this models the probability that a situation is occurring or not. The basic kinematic input parameters are deterministic, but the semantic interpretation of these data is highly probabilistic.

In a Bayesian belief network we can indicate the effect that an event has on another event by a probability number. Usually a huge data corpus is needed to compute the probability numbers in the Conditional Probability Tables (CPT's). But boats in danger are fortunately rare events. So it is impossible to gather data by logging data for some time to fill the CPT's. Military experts from the navigation section and experts from the Coast Guard were requested to set the probabilities in the CPT's. In Figure 9 we display an example of a Bayesian network. The probability of sensing an alert is computed at some given time. At regular times along a track of a boat the probabilities are computed again and again. To smooth the computed outcome we used Dynamic Bayesian networks. We used the Bayesian network toolkit developed at CMU (Genie, 2013). The results are promising. One of the problems we have to solve is that at this moment to many false positives are generated. The increase of the thresholds of the parameters will result in too many false negatives. Human operators in the Coast Guard center are able to handle false positives, but in full automated system this problem should be solved.
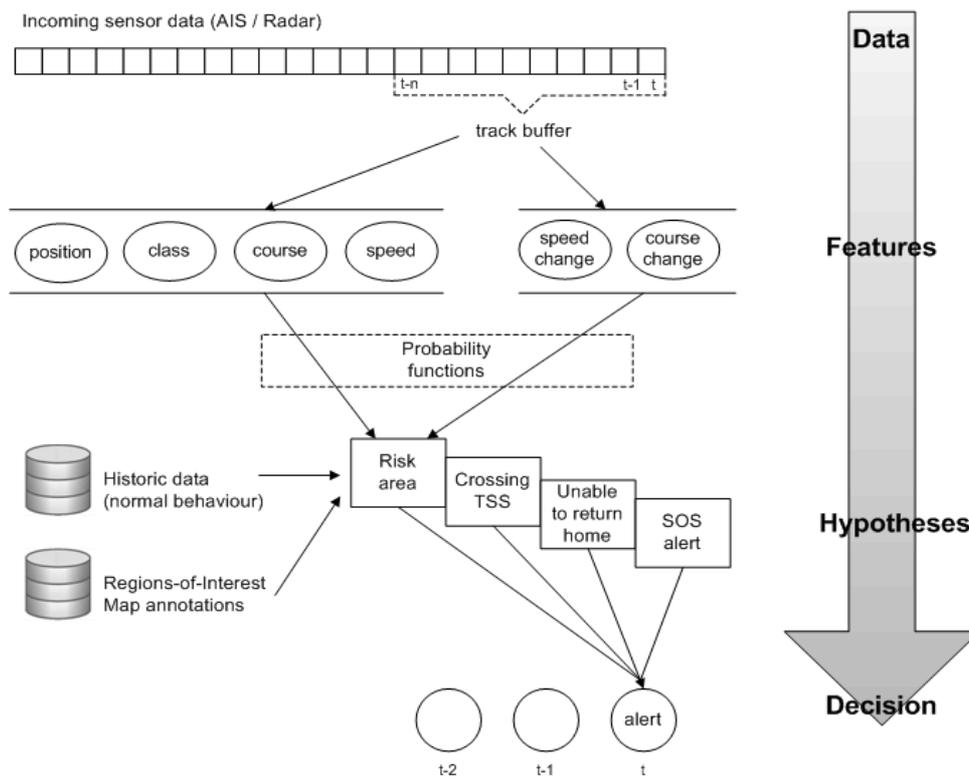
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Figure 8. Global processing scheme for determining suspect/danger level.
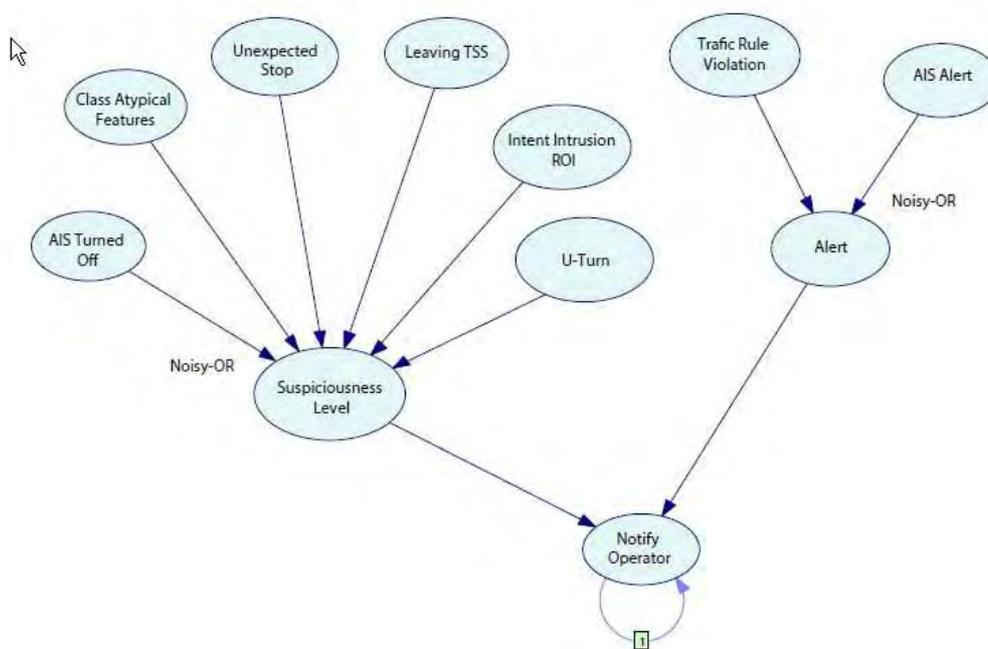

Figure 9. A Bayesian network scheme

ALERTING

In case of high risk an alert is send to the sailing boat from the Coast Guard. In section 2 we reviewed recent literature about early warning systems and listed some requirements for an alerting system using social media. An alert generated by our system has the following characteristics, and satisfies the requirements for state of the art alerting systems:

- *Personalization:* The static parameters of the boat are known by the system via AIS. This also includes a personal address, name of the boat etc. As soon an AIS system is installed on board permission is given to receive and process AIS data.

- *Context sensitive:* In the alert a situational explanation is given, including a risk classification, taking into account the context (current location weather and water conditions) and individual parameters of the boat.

- *Adaptive*: The alert recommends behavior that is used to adjust to another type of behavior or situation. The consequences of the general bad weather forecast are translated to the current boat and situation. Recreational sailors are tracked all the time. The reasoning module of the system includes the tracked parameters all the time.

- *Dynamic routing*: Weather and water condition change dynamically. A routing advice how to reach safe areas is based on this dynamic parameters, taking into account the context and individual parameters of the boat and of course the data on the annotated maps.

- *Evaluation*: After sending the personal alert the boat is still tracked to assess if the crew takes care or neglects the routing advice. The system evaluates if the recent track is in or heading to the safe corridor. The system has no emotion and will not be upset if the crew for whatever reason neglects the routing advice. But a boat on risk will receive new alerts very soon without reference to the preceding advices. This procedure is similar to dynamic car routing systems as TomTom.
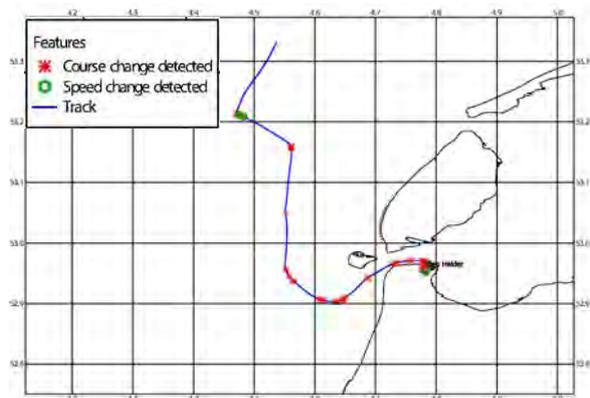
EXPERIMENTS

Figure 10. Track of a vessel returning home to the harbor at Den Helder

In this paper we report about a surveillance system including early warning. The backbone of the system is the AIS system, annotated maps, the ability to track vessels and to reason about those tracks. We were able to install our own AIS system and to log real life data. As mentioned before as soon a vessel is visible on the screen in the control room of the Coast Guard a surveillance agent is attached to it. The track will be logged and the crucial AIS parameters position, speed and heading are logged and analyzed. As a result we were able to visualize the tracks, change of speed and headings (see Figure 10). Finally with use of a Bayesian reasoning system the risk was computed. It proves that the system satisfies the technical requirements. Finally the system was tested on a day of bad weather conditions. The alerts were generated automatically and evaluated by experts from the Royal Marine. The experts were satisfied with the results. As stated before it proves that too many false positives were generated but more important no false negatives were missed.

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SUMMARY CONCLUSION AND FUTURE WORK

According to the yearly report (CostGuard,2012) the Coast Guard got 3073 requests for Search and Rescue from vessels on the North Sea, including 553 false alarms. This resulted in 1572 actions, and that is a lot. It is reported that in case the wind is stronger than 5 Beaufort even some cargo vessels had technical problems and were drifting away. A tugboat was needed to tow the vessel to a safe harbor. If we take into account that there are many more open waters, there is a need of an automated early warning system. Many private harbors along the open waters in the Netherlands take care of their sailing/motor boats. For their own safety even small boats have an AIS system installed. When boats leaving the harbor for a daily trip they give coded permission to track them. If the AIS system is switched off, the boat will be alerted via social media and checked for theft. At the end of the day there is a check if the boat has returned safely or has sent a message of possible delay. Owners of boats get customized to surveillance system and realize it is for their own safety. If an owner doesn't like to be tracked, he is able to switch of the AIS system. As a consequence the proposed system will be used all the time in good or bad weather condition. We were able to design a first prototype of a system which satisfies the requirements as defined in the introduction. The system was able to track and analyze the tracks of vessels using the AIS system. We designed a special knowledge base which contains the knowledge of the human operators at the Coast Guard center. We annotated the map of the region of the harbor of Den Helder using the AIS-logging data of boats. We used a Bayesian network system to compute the level of danger of the sailing boats. At this moment the prototype was tested by experts of the Royal Navy and operators of the Coast Guard center. During the development of the systems the experts of the center were already involved. In the meantime similar prototype systems will be developed for all the areas covering the open waters around The Netherlands.

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