Supervision concept for situated human driving applied to inland shipping

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Abstract— **In recent years, the need for networked and safe transport systems (vehicles, ships, trains, aircrafts) has increased. In inland waterway transport, remote-controlled operation controlled by a person at the same station on land, allows to increase the safety of traffic, might solve especially the problem of shortage of qualified nautical personnel, and reduces costs. Furthermore, the illustration of the decision behavior and the development of strategies for supervision of the captain-vessel-interaction are important for the realization of a work flowmanagement allowing the evaluation of the captain's actions, the detection and classification of errors, the suggestion of desired situation-related actions, and if necessary the take over of the driving functionality in case of critical situations.**
The contribution of this work is to propose a concept for supervision of the captain-vessel-interaction. The captain's behavior is mapped into a Situation-Operator-Modeling approach-based description to describe the real world actions as a graph-based-model allows to generate a net of upcoming actions depending on each other denoted as action space. A new kind of action space-based supervision is developed and the core of a work flowmanagement for the remotely operating human driving inland vessels. The main result of this contribution is related to the possibility and the illustration of the captain's interaction and decision behavior in specific maneuver situations.
Key Words: Inland shipping, Captain-Vessel-Interaction, Supervision of Captain-Vessel-Interaction, Situation-Operator-Modeling (SOM)

I. INTRODUCTION

Safety requirements in inland shipping and the demand of connected traffic are of increasing interest. The development of a ship's command realized by a person requires the mapping of the captain's behavior, which must be integrated into the remotely controlled operation as a monitoring system, is a possible solution. In addition, monitoring strategies are necessary for the illustrated captain's behavior so that actions can be evaluated and errors can be detected.
In previously works, the illustration of the captain's behavior and supervision strategies applied to the captain-vessel-interaction are hardly discussed. In [8] the authors present a study for the investigation and examination of human factor issues for autonomous unmanned vessels supervised by an operator onshore. Five participants (four master mariners and an engineer) take part in scenario-based trials and interviews over a two-day period [8]. In the review [6] human factor issues related to remote ship operations are classified and whose affecting to Human-Machine-Interactions is discussed. A Human Factors Analysis and Classification System-Martime Accidents framework [10] is used for an expert study presented in [15] to analyze the influence of Human Factors on the safety of remotely-controlled merchant vessels. To improve the decision-making process and support operators domain a quantitative situation awareness model applied to a system safety control structure of remotely controlled vessel is proposed in [16] using mathematical framework of hierarchical Bayesian Inference. The literature [13] presents and discusses strategies for the safety management in remotely-controlled vessels. In [4] the authors investigate the roles of human factors in marine accidents and analyze marine accidents reports from the MAIB database (Marine Accident Investigation Branch). In [7] a concept using a Success Likelihood Index Method is developed to predict the human-machine interface-based operational errors of remote-control maritime autonomous surface ships.
A Situation-Operator-Modeling approach is developed in [11] allowing the modeling of human-machine-interaction as a cognitive technical system and the changes from outside world. Using this approach supervision methods for human-machine-interaction are proposed in [12]. The SOM-approach is used for the modeling and supervision of Human-Machine-Interaction in several domains. In [1] cognitive modules (Planning, learning, plan supervision) are presented and integrated in an architecture allowing cognitive control of an autonomous mobile robot. A SOM-based concept for an automated supervision applied to Driver-Vehicle-Interaction is proposed in [12] and implemented using Higher Petri-Nets (cf. [2]). The SOM-approach is combined with the Safe System surveillance and control to develop a fall-back layer for aerial systems allowing the determination of risk areas in real-time [3].
The contribution of this work is to propose a SOM-based concept allowing situated supervision of remotely human-operated sailing of inland vessels. Furthermore, the calculation of an action space consisting of possible actions is presented. This paper is organized as follows. In section II the Situation-Operator-Modeling approach used for the illustration of the captain's behavior is defined. The results are shown as an application to an example driving scenario in section III. The concept of the supervision for the captain-vessel-interaction, the strategies for the evaluation of captain'

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actions, and the detection of missing actions is discussed in section IV. The development of an action space including supervision methods using an example demonstration is shown in section IV.

II. Situation-Operator-Modeling

The Situation-Operator-Modeling approach is developed to model the Human-Machine-Interaction and to illustrate changes and scenes from the real world to a model represented as a graph-based-model [11] (cf. Fig. 1). The SOM approach allows the modeling of changes in real world as sequences consisting of items scenes and items actions by using the related terms situation and operator allowing to build an inner structure of the model of the required operation as interaction between a guiding human operator and a technical systems [11]. A scene is modeled as a situation and an action as an operator. In Fig. 1 a sequence consisting of a current situation S_i, a current operator O_i, and the following situation S_{i+1} is depicted as a model-illustration [11]. Each operator connects the actual and the following situations with each other and is therefore connected to them.

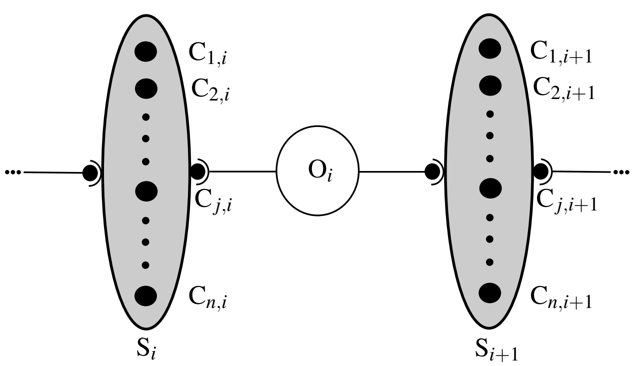

Fig. 1. Action sequence modeled as Situation-Operator-Situation sequence [11]

According to Fig. 1 a situation is graphically represented as a gray ellipse describing a situation vector including characteristics and a white circle refer to an operator.
According to the SOM definition a scene is modeled as a situation describing the internal structure of a system and is situated, so related to a fix problem configuration in contrast to the definition given by [9]. Each situation includes a set of characteristics C, which can be physical, logical, functional, or informational terms and is expressed by related values [11].
Changes and actions in the outside world are modeled as active operators connecting the situations with each other [11]. An operator is defined by its functionality denoted by F related to explicit and implicit assumptions, which models explicitly or implicitly assumptions described by suitable mathematical, logical, or textual expressions [11]. An operator connects the current situation with the following situation. This means, that an operator can effect the structure and the values of the characteristics in the following situation. Depending on the application operators or predefined situations related to specific problems/tasks can be stored as knowledge base.
The existence of a human-machine interaction modeling approach allows the development of cognitive functions and in combination with a stored memory the procedures allowing the cognitive control of intelligent systems. This cognitive functions are learning, planning, acting, and supervision [11]. In this work, planning, acting, and supervision modules for the captain-vessel-interaction are designed, implemented, and applied. In this contribution learning is not of relevance, knowledge, relations, the situation structure, operator and situation connections are predesigned by expert knowledge. Planning and acting according to the Situation-Operator-Modeling approach mean establishing sequences from the actual situation S_i to a desired situation S_d describing the desired final situation. Modeled operators from the knowledge base are used and connect the situations with each other leading to the desired situation [11].

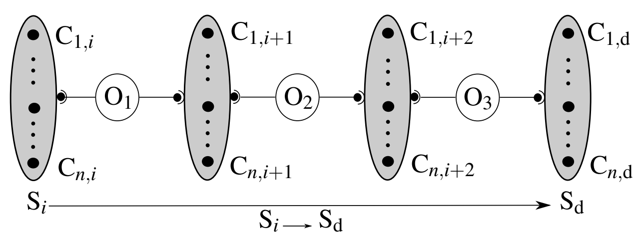

Fig. 2. Sequence based on Situation-Operator-Modeling [11]

III. Modeling human operator's decision behavior when driving inland vessels

According to the SOM-representation a sequence consists of operators and situations including characteristics. Operators and characteristics can be obtained by considering and analyzing real scenarios.

TABLE I
List of characteristics including in the situation vector

Name and description of characteristic	Unit	Typ
C_1 : Speed Over Ground	[km/h]	Real
C_2 : Course Over Ground	[°]	Real
C_3 : State of the throttle	[%]	Real
C_4 : Acceleration	[km^2/h]	Real
C_5 : Bow thruster for steering (C_1<6 km/h)	[°]	Real
C_6 : Rudder for steering	[°]	Real
C_7 : Blue board (passing on starboard side)	[-]	Boolean
C_8 : Water flow	[-]	Boolean
C_9 : Availability of berth	[-]	Boolean
C_{10}: Suitability of berth for vessel's class	[-]	Boolean
C_{11}: Distance to berth	[m]	Real
C_{12}: Checking, ob driving area is free	[-]	Boolean

In Table I the characteristics describing the inner structure of a situation for the case of captain-vessel-interaction are shown. This characteristics can be physical (for example C_1,

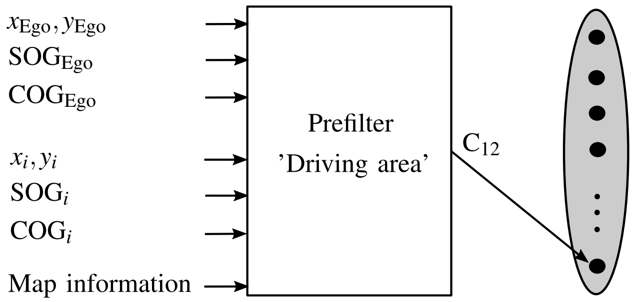

Fig. 3. Prefilter „Driving area"

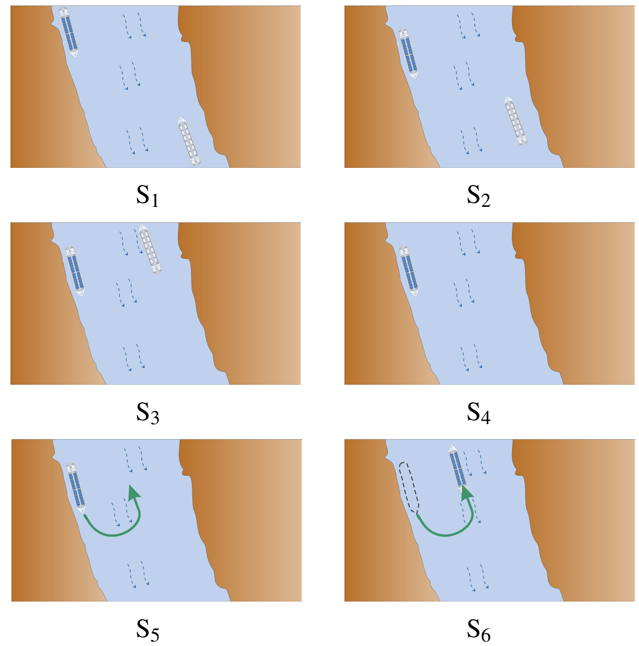

Fig. 4. Visualization of a 'Turn around'-maneuver: ego-vessel (blue), encountering vessel (white)

C_2 ect.) or informational (for example C_7, C_8 ect.).
Prefilters allow the compressing and fusion of information and the extracting of values for related characteristics. The characteristic C_{12} is obtained from the prefilter 'Driving area' (cf. Fig 3), so the output of the prefilter 'Driving area' can be mapped directly as actual value of the related characteristic C_{12}. The characteristics C_9, C_{10}, and C_{11} are the outputs of the prefilter 'Berth'. In this work only the prefilter driving area is needed for the illustration of the 'Turn around'-maneuver shown in Fig. 4. The prefilter „Driving area" allows the statement about the availability of the driving area with a given radius. The related statement about the accessibility is consequently 'True' or 'False'. The inputs are map information, Speed Over Ground, Course Over Ground, and the position of the Ego-vessel as well as the other vessels in the driving area (cf. Fig 3). The situations are connected with active operators stored in a knowledge base. The operators used for the illustration of the captain's behavior are illustrated in the Table II.

TABLE II
LIST OF OPERATORS

Name of operator	Requirements and description
O_1 : Acceleration	Pressing the throttle
O_2 : Deceleration	Pulling the throttle
O_3 : Waiting	Doing nothing
O_4 : Maneuver to the right	Using bow thruster clockwise
O_5 : Maneuver to the left	Using bow thruster counterclockwise
O_6 : Route trip to the right	Operate Rudder clockwise
O_7 : Route trip to the left	Operate Rudder counterclockwise
O_8 : Blue board	Activate the blue board

The Situation-Operator-Modeling can be applied to a 'Turn around'-maneuver shown in the Fig. 4. The blue vessel refer to the Ego-vessel and other vessels are in white. The graph-based-model obtained from the Situation-Operator-Modeling is developed as depicted in the Fig 5.
In the initial situation S_1 the captain reduces the speed of the vessel and this action is modeled with the operator O_2 „Deceleration". The captain has to consider the encountering vessel and to wait (operator O_3 „Waiting"). The driving area is in the situations S_1 and S_2 not free and the characteristic C_{12} provides the logical information „False" (cf. Fig 5 and Table I). The driving area is free in the situation S_3 and the characteristic $C_{12,3}$ related to the checking of the driving area changes to „True". The captain prepares the steering to the left by operating the bow thruster (operator O_5) and the rudder (operator O_7). The operator O_5 effects the following situation S_4 by changing the value of the characteristic $C_{5,4}$ describing the state of the bow thruster (cf. Fig 5). The value of the characteristic $C_{6,4}$ related to the state of the rudder changes after using the operator O_7 (cf. Fig 5). The captain accelerates (operator O_1) and the Speed Over Ground described by the characteristic $C_{1,6}$ increases (cf. Fig 5).
The sequence shown in Fig. 4 and SOM-based mapped in Fig. 5 leads to the desired final situation. Errors of the captain's behavior are not detected. In other cases the desired final situation can not be reached because the captain's behavior is not correct or not optimal considering the assumptions and the actual situation. The actions of the captain are monitored and missing or wrong actions should be detected. The supervision strategy allowing the analysis of the captain's behavior and the detection of missing actions as presented in the next section. Subsequently an action space consisting of possible captain's behaviors of the sequence in Fig. 4 has to be developed as shown in section IV.

IV. Supervision of the Captain-Vessel-Interaction Using the Action Space Notation

To increase the system safety of the overall system, the monitoring of the captain-ship interaction and in this context the analysis of the actions as well as the detection of human errors is necessary. A SOM-based strategy [12], will be applied to the captain-ship Interaction as shown in Fig. 6. The basic dynamics patterns refer to sequences of

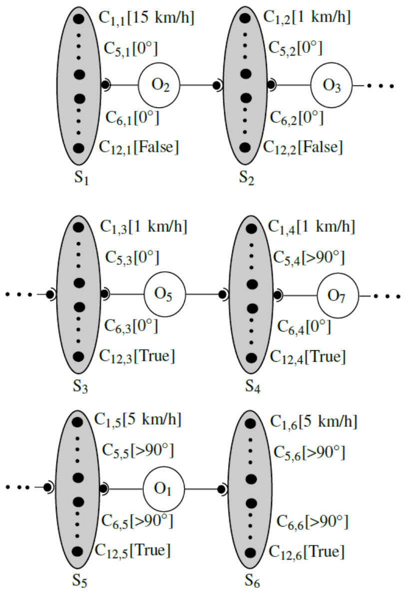

Fig. 5. Graph-based-model using the Situation-Operator Modeling of the driving scenario 'Turn around' shown in Fig. 4

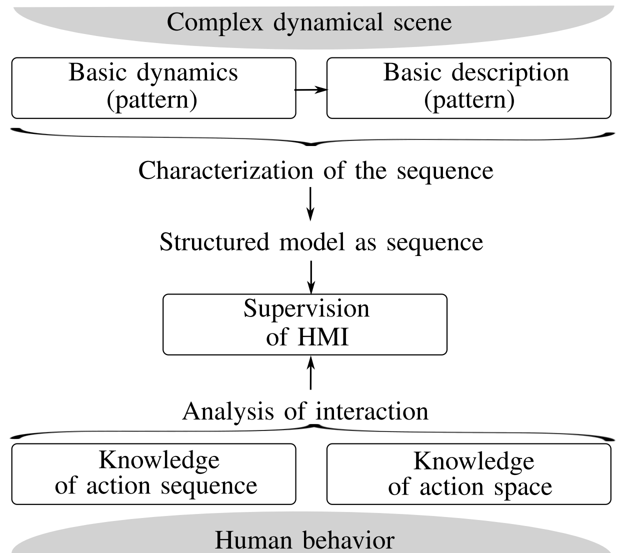

Fig. 6. SOM-based supervision for Human-Machine-Interaction according to [12]

the interaction patterns refer to sequences of actions and scenes as realized in real interactions. These actions and scenes will be modeled as situations and operators (basic description patterns). The developed model consists of a structured, situation- and task-related sequence of situations and operators. The features contained in the situations are partly generated by a suitable processing (prefilter) whereby measured variables are combined in a problem-oriented way to generate compressed or problem-oriented information based on sensor data (AIS data, maps). The logic of the action patterns contains formalized operators, which link the situations and represent the suitable captain's behavior. Based on these formalized operators, the correlations with the situations, errors (and error patterns) of the human-machine interaction can be captured. The monitoring of the human-machine interaction is therefore based on the problem-related, situated model. Only with the use of this underlaying the background of this structure (the meaningful sequences of actions) the interaction between the human and the technical system can be evaluated.

For the analysis of the captain's behavior and the detection of missing actions of the captain a SOM-based concept is proposed. This concept consists of a lower level (selection of partial sequence related to the desired situation-oriented action) and a higher level (checking of assumptions for the current operator, human errors, goal conflicts). In the lower level the actual action of the captain is chosen and compared with a partial sequence related to the desired situation-oriented action. The higher level can be used to check the assumptions for the actual operator, the human errors, and goal conflicts. Based on this strategies a concept for the distinction between

i) inadmissible operators,
ii) operators with respect to assumptions, and
iii) operators with respect to desired final situation

is possible and can be applied to the captain-vessel-interaction for evaluation of captain's actions. For example operating the bow thruster to the right in the situation S_3 leads in next situations to a collision against the river bank. The Operator O_4 (Maneuver to the right) as well as O_6 (Route trip to the right) are classified as inadmissible. In the situation S_5 the captain could decelerate, so that the vessel turns around backwards and against the direction of the water currents (cf. Fig 4). Turning around against the direction of the water currents is possible but less meaningful than turning around in the direction of the water currents by accelerating. The operator O_1 (Acceleration) describes in this situation the optimal action and is classified as the operator with respect to the desired final situation, when the operator O_2 related to the deceleration is classified as an operator with respect to the assumptions.
With the knowledge of the relations for the detection of human errors and the evaluation of options for action (for the usual case that there is more than one option to achieve the desired target situation), a continuous analysis of actions can be performed. The core here is the so-called action space consisting of permissible operator sequences in relation to the known or further meaningful action desired final situation, so that monitoring strategies can be developed accordingly. In previous works [14] [5] the SOM-approach is applied to describe the human's behavior as a graph-based-model. In [14] the authors develop a situated action space as the core of an driving assistance system allowing the prediction of the driver's intention. The SOM-approach is used in [5] for the calculation of an action space to analyze the human decision making in air traffic control.

In this work the 'Turn around'-maneuver (cf. Fig. 4) is considered as example.
In Fig. 7 possible driving scenarios that have the desired final situation 'Turn around' are shown. Only driving scenarios that refer to permissible operators are considered. Situations that do not lead to the desired final situation or could lead to dangerous situations (based on directly impermissible actions) are not considered here. In the concrete example, four possible paths lead to the desired final situation (cf. Fig 7). This possibilities are explained as follows:

Possibility 1: In this case the captain accelerates in the situation S_2 and passes on the encountering vessel. The driving area is free in the situation S_3. After operating the bow thruster and the rudder, the captain decelerates and turns around backwards (direction of the 'Turn around'-movement in this case as a yellow arrow). The 'Turn around'-maneuver in this case leads to the desired final situation, but turning around against the direction of water currents is not meaningful. This action is classified as operator with respect to the assumptions.

Possibility 2: In this case the captain accelerates in the situation S_2 and passes on the encountering vessel. The driving area is free in the situation S_3. After operating the bow thruster and the rudder, the captain accelerates and turns around in direction of the water currents (direction of the 'Turn around'-movement in this case as a blue arrow). The 'Turn around'-maneuver in this case leads to the desired final situation and the action is classified as operator with respect to the desired final situation.

Possibility 3: This case is the same driving scenario shown in Fig. 4. The captain considers the encountering vessel and the driving area is in the situations S_1 and S_2 not free. The driving area is free in the situation S_3. After operating the bow thruster and the rudder, the captain accelerates and turns around in direction of the water currents (direction of the 'Turn around'-movement in this case as a green arrow). The 'Turn-around'-maneuver in this case leads to the desired final situation and the action is classified as operator with respect to the desired final situation.

Possibility 4: The captain considers the encountering vessel and the driving area is in the situations S_1 and S_2 not free. The driving area is free in the situation S_3. After operating the bow thruster and the rudder, the captain decelerates and turns around backwards against the direction of the water currents (direction of the 'Turn around'-movement in this case as a red arrow). The 'Turn around'-maneuver in this case leads to the desired final situation, but turning around against the direction of water currents is not meaningful. This action is classified as operator with respect to the assumptions.
Considering the direction of the water currents, four possible behaviors could lead to the desired final situation, but only two behaviors are meaningful. The graph-based representation is shown in Fig. 8. The action space is developed according to the SOM-definition consisting of operators and situations depending to the assumptions of the environment. The advantage of the development of an action space is to support the captain by suggesting useful operators and possible paths leading to the desired final situation, which are included in the action space. In the case, that the captain's action is not included in the action space and could lead to dangerous situations, the driving functionality can be given to an autonomous operation unit also using the existing action space.

V. CONCLUSIONS

In this work the development of an action space allowing the supervision for situated human driving applied to inland shipping is realized. The Situation-Operator-Modeling approach is used to model the captain's behavior as a graph-based-model and is applied to an example driving scenario. The principle strategy for human error detection and also not optimal behaviors are developed as base for supervision strategies. Related supervision strategies are applied to the captain-vessel-interaction to analyze the captain's behavior, the evaluation of the captain's actions, and the detection of missing actions. The supervision strategy is integrated in the action space consisting of possible paths leading to the desired situation. The action space of an example driving maneuver is shown and discussed.
The presented approach for determining action spaces and detecting associated faults will improve the performance of action logic-based monitoring and supervision methods in the future. Future work will focus on real-time implementation.

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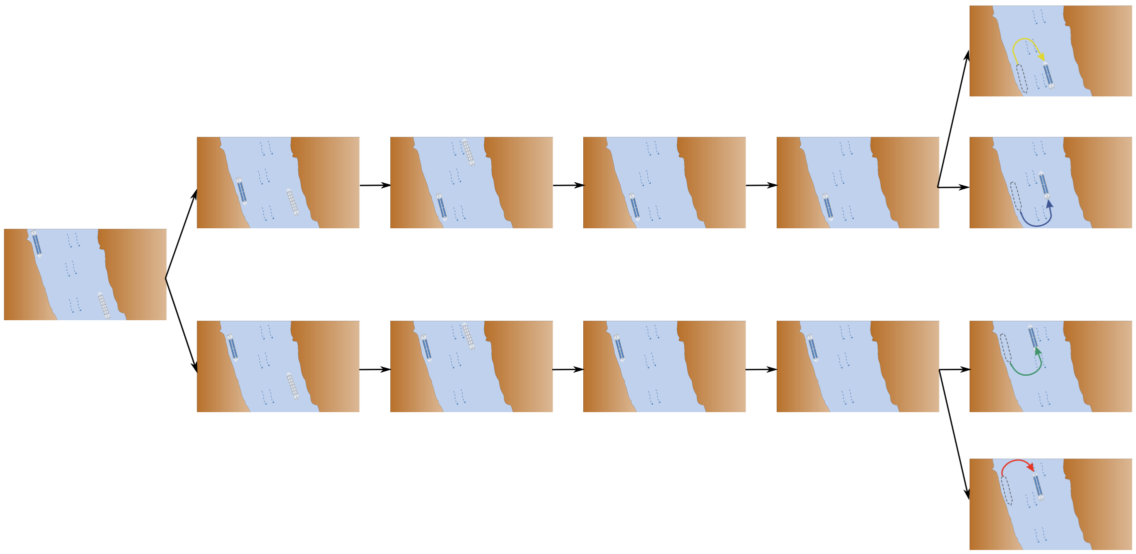

Fig. 7. Possible paths to reach the desired final situation 'Turn around'

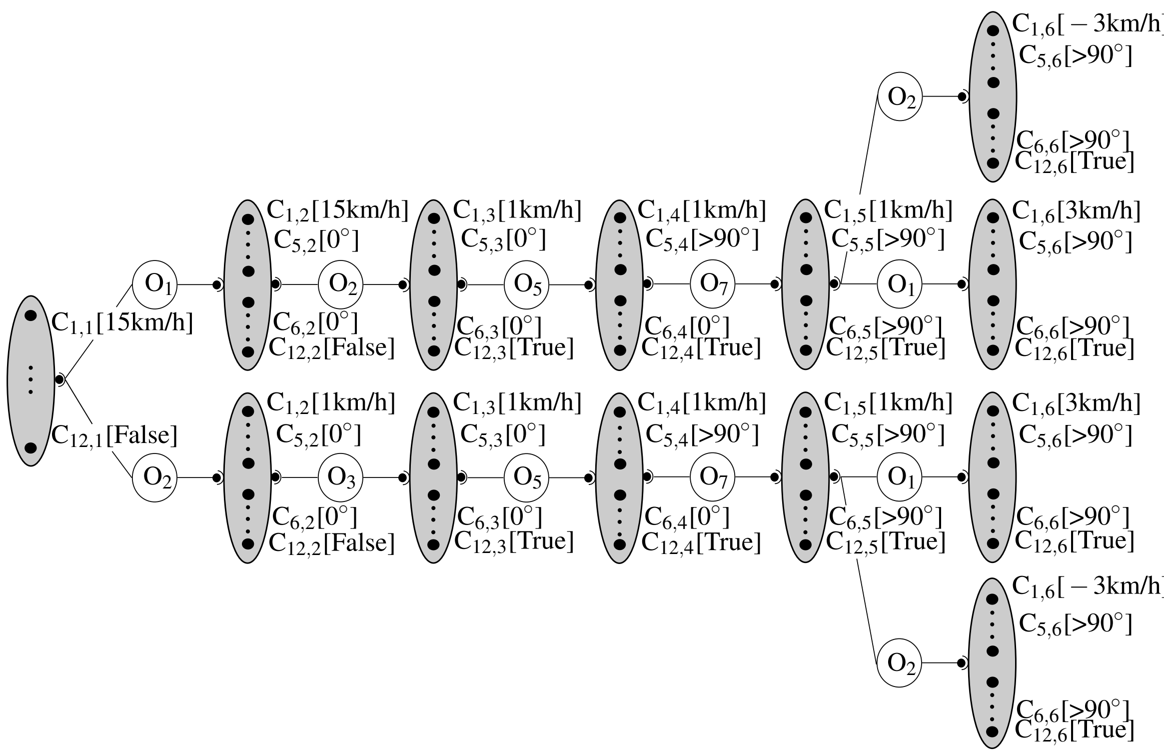

Fig. 8. SOM-based Action space of the 'Turn around'-maneuver (cf. Fig. 7)

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