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Modern automation tasks of underwater complexes with umbilical tethers

***Abstract**. The paper reports the features of underwater complexes with umbilical tethers as control objects and their control problems. The definition of underwater complex with umbilical tethers is given, its salient features are described. The characteristics of a naval moving object and an umbilical tether as control objects within underwater complex are given.The modern tasks of underwater complexes with umbilical tethers automation are lined up.*

Keywords: automatic control system, remotely operated vehicle, underwater complex, umbilical tether.

Introduction

An underwater complex with umbilical tethers (UCUT) is the class of naval techware applied for wide range of underwater tasks solving. It originates from classic tethered underwater systems (TUSs) which are well known and described in scientific literature [1] and it is their generalization.

The typical single-chained TUS includes a remotely operated vehicle (ROV) connected by umbilical cable to a vessel that is located on water surface. The ROV is the processing equipment carrier and the underwater task solver, the vessel's task is to deliver the ROV to the work area and to supply its functioning. The umbilical cable is used to supply the ROV with energy and to provide data exchange between the ROV and the surface control unit.

The TUSs development comes in tendency that the vessel's role becomes less supplying and more involved into technological process. Within new systems the vessel is replaced by a surface remotely operated vehicle. And the salient feature of such systems is still the existence of mechanical connection between their elements by an umbilical cable. That is why the classic TUSs (with self-propelled, towed, bottom, dipping, other types of ROVs) and their modern variations are the instances of the same UCUT class.

Single-chained UCUTs are used for simple tasks in shallow water. More demanding deep water objectives or wide area search technologies need to involve multi-chained UCUTs. Nevertheless to improve the efficiency of even single-chained UCUT the automation of its spatial motion is needed. As for multi-chained UCUTs it is hard to perform even simple tasks by manual control, not to mention complicated underwater technologies realization.

The underwater complex with umbilical tethers as a control object

Generally UCUT consists of lumped parameters elements connected by distributed parameters elements. The lumped parameters element is a naval movable object (NMO): a ship, a submarine, ROV etc. The distributed parameters element is an umbilical tether (UT): a towing cable, a fiber optic cable etc.

The general UCUT features are:

- all the UCUT's NMOs are mechanically connected with each other by UTs, this connection could be direct between two NMOs or indirect, i.e via third NMO;

- two NMOs connected by a UT make a UCUT;

- at least one UCUT's NMO must be submersible.

The main UT parameter is its length L which is separated on the released part L_r and coiled part L_c: $L = L_r + L_c$.

The released part is located in the environment (mainly in water or in air), moves and interacts with it. The coiled part is located on a vessels deck or on a winch and moves with the NMO to which the winch is fastened.

The main controlled parameter of UT is L_r which can be changed by controlled cable winding or unwinding and by uncontrolled tension force action that is considered as a disturbing influence.

The spatial UT location is represented by its axial line which can be given as a curve spatial vector equation:

$$\vec{r} = x(s)\vec{i} + y(s)\vec{j} + z(s)\vec{k}, \quad s \in (L_c, L];$$

where $\vec{r}$ – radius-vector of a point located on a UT axial line; s – UT arc coordinate, $x(s)$, $y(s)$, $z(s)$ – parametric equations of UT progressive coordinates in space. The part with arc coordinates $s \in [0, L_c]$ is coiled.

It is possible to control the motion of fast and root ends of UT because they are fastened to NMOs. The rest UT points are controlled indirectly by NMOs movement and by L_r changing.

Operating a UT could result in its parameters unsteadiness conditioned by temporal or situational factors. The first one appears in consequence of UT materials degradation and deterioration. The second one appears as a result of hydrostatic pressure and leads to inequality even of parameters that were designed to be independent of *s* such as cable diameter, buoyancy, hydrodynamic coefficients.

The NMO is a firm object with six freedom degrees. It can implement controlled motion under influence of at least one of factors:

- UT influence, the controlled UT length changing could cause desired NMO kinematic parameters changing;

- passive interaction of NMO's bearing surfaces, rudders tail fins etc. with environment;

- active interaction of propulsors with environment.

The NMO's spatial motion splits to six simple motions: three progressive motions and three rotary motions (one motion per freedom degree), each motion is presented by positional and velocity kinematic parameter.

Depending on NMO's controlled motion capabilities the control task can be split to simple tasks which include progressive and rotary components and each component is formed from union of positioning and trajectory movements (table 1).

The UCUT control tasks are represented by combination of its NMOs control tasks supplemented with UT length control. For example when performing an underwater straight pipeline inspection vessel's and ROV's tasks consist of trajectory movement by 1 coordinate (along the pipeline) within the progressive component and positioning by 1 coordinate (course keeping) within the rotary component, the cable winch task is to regulate the UT length to keep the tension force at minimum.

Different UCUT configurations have similar features that make it possible to consider control automation within single theory.

Table 1. Simple control tasks of NMO.

Task components	Positioning	Trajectory movement
Progressive component	by 3 coordinates (at point)	none
	by 2 coordinates (at line)	by 1 coordinate (at line)
	by 1 coordinate (at flatness)	by 2 coordinates (at flatness)
	none	by 3 coordinates (spatial)
Rotary component	by 3 coordinates	none
	by 2 coordinates	around 1 axis
	by 1 coordinate	around 2 axes
	none	around 3 axes

The underwater complex with umbilical tethers automation problems

Today the particular regimes of UCUT motion are automated: NMO heading and depth stabilization, NMO speed control etc. [2]. But to comply with modern control quality demands it needs to be considered within complex UCUT automatic control theory.

It is proposed to perform the UCUT automatic control system synthesis by consecutive solving of three basic problems (fig. 1), which are complicated by uncertainty of UCUT elements and environment parameters.

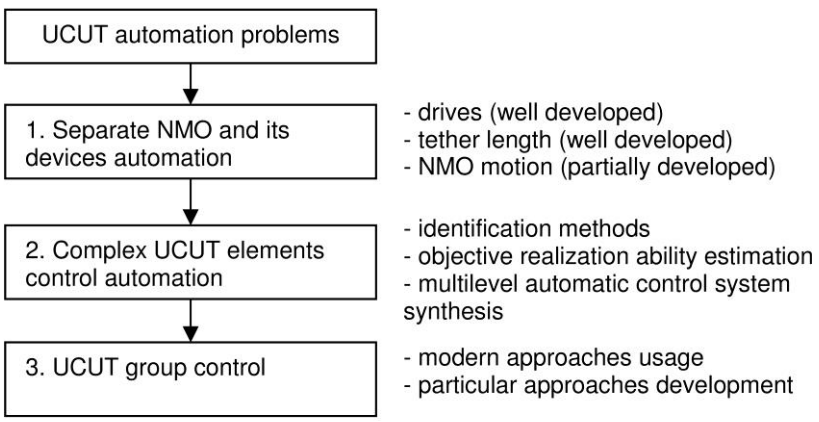

Fig. 1. UCUT automation problems and basic tasks.

First problem covers automation of NMO and its devices and consists of:
- drives and actuators automation;
- umbilical tether length control automation;
- NMO spatial motion automation under the umbilical tethers influence.

The modern automatic control theory has got solutions for the first problem: the automatic control systems of typical drives and actuators are well developed and have practical usage, the UT length control is achieved by automatic winch control systems, and the particular motion regimes of certain NMO types are automated. But development and usage of NMO of new structural types still demand development of new automatic control systems which is one of the UCUT automatic control theory tasks. Also the UT affects greatly on NMO's motion. It should be considered that NMOs of multi-chained UCUT could suffer the uncertain influence of more than one UT, so the typical NMO spatial motion automation solutions could barely give the desired control quality.

Second problem covers UCUT elements control automation as a single complex taking into account their interdependence and could be solved if the first problem is solved successfully. At present it is almost unexplored and so it forms a list of UCUT automatic control theory tasks:

- structural and parametric identification methods development;
- UCUT objective realization ability estimation methods development;
- UCUT multilevel automatic control system synthesis methods development.

Third problem – UCUT group control – is based on successful solving of second problem and modern approaches to the group control automation [3] and also needs to be developed to improve wide area search and survey efficiency.

The complete consecutive solving of the main problems evolves the UCUT automatic control theory and makes it possible to use similar methods for synthesis of different UCUT configurations automatic control systems.

Conclusions

1. The definition of underwater complex with umbilical tethers is given, the similar features of such complexes are marked out that make it possible to consider their different configurations control automation within single theory.
2. The characteristics of a naval moving object and an umbilical tether as control objects within underwater complex are given that forms the basis for modern automation problems and their tasks formulation.
3. The modern problems and automation tasks of underwater complexes with umbilical tethers are lined up, their consecutive solving evolves the underwater complexes with umbilical tethers automatic control theory.

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