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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (17): 4212-4217, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.4212.4217

Information Fusion in Motion Control of Underwater Vehicle

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Abstract: Great successes have been made in applications of information fusion in the mode recognition and state evaluation. It is the same that the application of information fusion in the motion control system of underwater vehicles will greatly promote the development of control technology. This study proposes a layered multi-loop control system used the technology of information fusion. It recurs to the layered fusion and multi-level feedback of information to perfect the control system and then improve the control performance and intelligence behaviors of underwater vehicles.

Key words: Underwater vehicle, information fusion, obstacle avoidance, fault diagnosis

INTRODUCTION

The accuracy of data from each sensor is very important for the running of vehicleic system or other automatic systems. But the invalidation, noise and limited resolution which are related to sensors, restrict the performance of system or even result in system failure. Using multi-sensor system to fuse sensor data may stabilize or improve the performance of the system.

Why apply multi-sensor information fusion technology to underwater vehicles motion control system is that control signals in a sense can be thought of as fusion results of sensor information, objective information and control object knowledge information and so on (Xu *et al*., 2006; Xu and Xiao, 2007). Broadly, information fusion can be regarded as a process in which information is mapped from n-dimension space to m-dimension space by certain regulation (in general, m is less than n, but we could take m as an arbitrary positive integer). And the fusion result could be the induction and abstract, recognition and learning (up) of original information, or could be the subject's reaction and feedback to the environment, decision and action signals (down). From biological point of view, the given rules of information fusion (in/out relationship) come from inheritance combined with selection, or from subjective learning. Therefore, control signals are fusion results (Liu *et al*., 2002; Liang *et al*., 2006). Especially, collision avoidance can be looked as the proper fusion of vehicle motion, obstacle information, vehicle hydrodynamic knowledge and vehicle self-protecting consciousness. Moreover, the hydrodynamic knowledge of vehicle itself is the result of information fusion (Li *et al*., 2005).

The research of neurophysiology has shown that there is compact coupling feedback control in the fusion process and the feedback control signal usually is the output of fusion process. So the basic motion control proposed in this study right is the simulation of the biological information fusion process. And this kind of control based upon information fusion can run on relatively lower fusion level which still belongs to reflex category. Thus, it will have good real-time quality, parallel and distributing quality and it can reduce the burden of central processor (Logic Deductive Unit) effectively. Moreover, reflex behavior based on multi-sensor information fusion should be more sensitive, robust and reliable than that based on simple information.

The highlight of this study is to deal with motion control problem as information fusion and the generating process of control signal is the right process of information fusion which is fit for control object. In a word, according to this point of view, we are intending to research the application of multi-sensor information fusion technology to underwater vehicles motion control system which differs a little from traditional research. Taking redundancy and different types of sensor' data, such as sonar data (including collision avoidance sonar and distance sonar etc.), underwater photic-vision data and underwater navigation data (including position, pose data and corresponding velocity values) as fusion object, the purpose of this study is to achieve that: (1) Decreasing the negative influence of low resolution and high invalid-point rate of sensors, (2) Improving navigation accuracy and (3) Improving the performance of controller and responding speed for emergency. It is one of key technologies to use navigation and environmental obstacle information from sensors to work out robust motion control responses under most emergencies which must be broken through for underwater vehicles to accomplish missions automatically.

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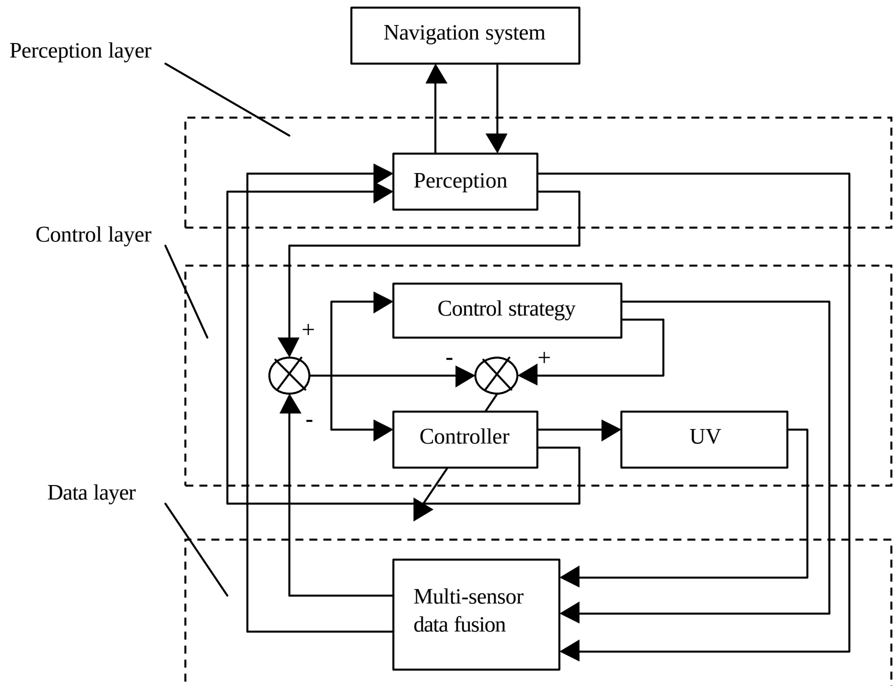

Fig. 1: motion control system of underwater vehicle (UV)

APPLICATION OF INFORMATIONG FUSION MOTION CONTROL OF UNDERWATER VEHICLE

In view of the hiberarchy of multi-sensor information fusion and motion characteristics of underwater vehicles, three layers of multi-sensor information fusion are presented in the motion control system of underwater vehicles, data layer, control layer and perception layer.

Here navigation system is an upper layer about artificial intelligence which isn't discussed in this article. The navigation system is mainly in charge of disassembling of mission, programming and decision- making while motion control system are mainly in charge of the perception of environment and the system itself and the control of thrusters to implement objects prescribed by the navigation system. It is very useful for control system to perceive the collision danger around underwater vehicles and make responses most quickly which can improve vehicle's survival capability greatly. The perceptions of system performance and thruster status are also of great avail to the design of controller and the choice of control mode. Therefore, the perception capabilities are integrated into control system of underwater vehicles to improve the performance of control system in the aspects of data processing, controller optimizing and fault finding etc.

Original information from sensors and some fusion information of upper layers (control strategy) are fused in the data layer (Liang *et al*., 2011). Of course, as for the control system in this article, two aims are to be fulfilled. One is target of navigation, the other is rapid obstacle avoidance of lower layer (similar to the non-conditional reflex of human). These should be two kinds of fusion in data layer, the first is to fuse positioning data to get the vehicle's motion information, the second is the fusion of audio-vision, laser telemeter and obstacle avoidance etc. to get the relative information between obstacles and vehicle. The disposal methods can be same, though there are two different kinds of fusion. It is the purpose of the data layer to fuse data of many sources (both in regions of space and time) to improve data's reliability and accuracy by means of hardware redundancy and analytical redundancy. Because of the frequent failure phenomena of underwater sensors, the first step of fusion should be fault diagnosis of sensors, at the same time cutting data from the failed sensor; the second step is to fuse data spatially from sensors that are working properly; and the last step is fusion according to time. Common methods in this field are Bayes estimation, multi-Bayes estimation, Kalman filter, Dempster-Shafer proof reasoning, spawning formula having probability factors, the least expression of information theory based on

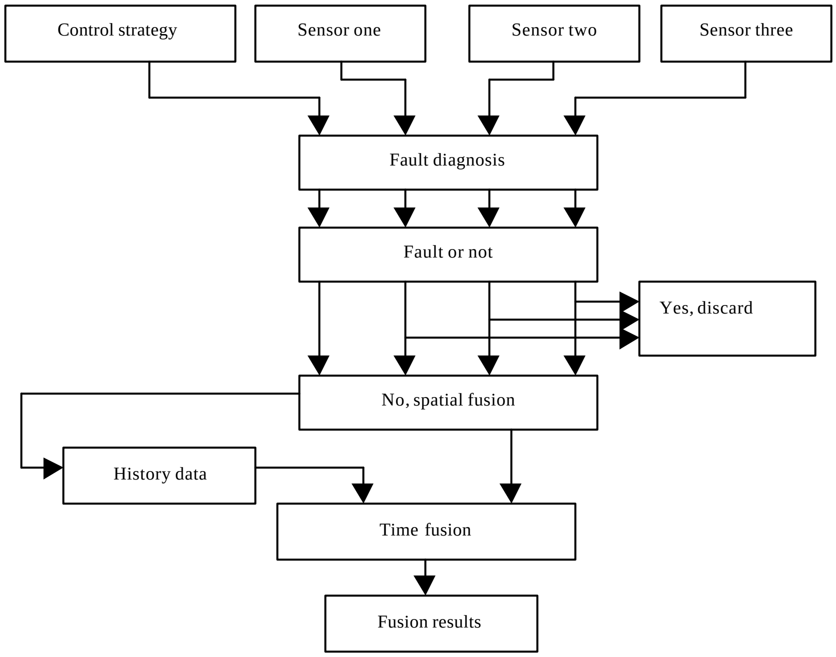

Fig. 2: Fusion of data layer

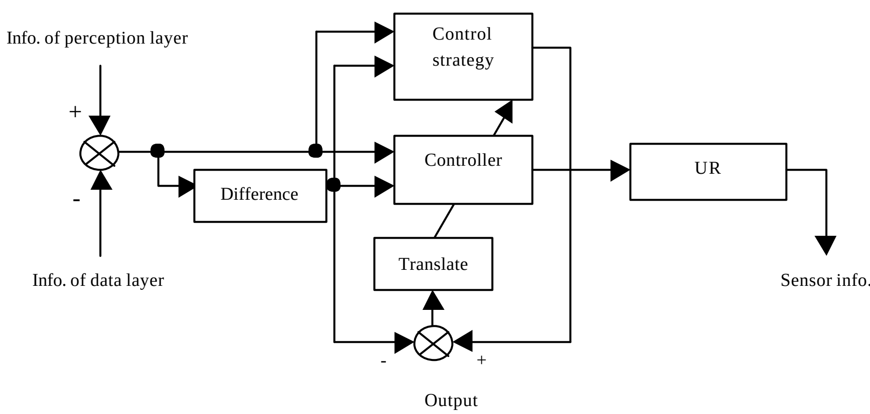

Fig. 3: Flow of control layer

model, fuzzy logic, neural networks etc. In practical research, the team harmony method was adopted in this study (Zheng, 2010).

The flow figure of control layer is described in Fig. 3, in which the infor- mation of perception layer is the target position and the information of data layer are current position of underwater vehicles fused in data layer. When we use velocity sensor, the information of data layer are current velocities, correspondingly, the differential model in Fig. 3 should be an integration model.

Error of output and the change of error can be obtained by disposing differences between target position and underwater vehicles position. Control strategy embodies the motion capacity of underwater vehicles and the underwater vehicle is controlled according to it to fulfill requested assignments, such as positioning, goal guiding and trajectory tracking. Considering of ocean movement, the error between the real motion of underwater vehicles and the expected one of control strategy are used for the parameter learning of adaptive controller.

The perception technology of underwater vehicles is very difficult when applying artificial intelligence to underwater vehicles which includes the obtaining and

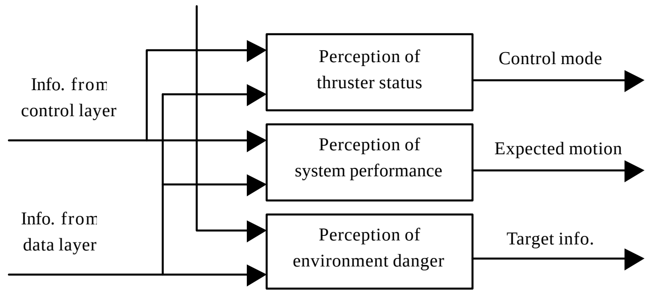

Fig. 4: Flow of perception layer

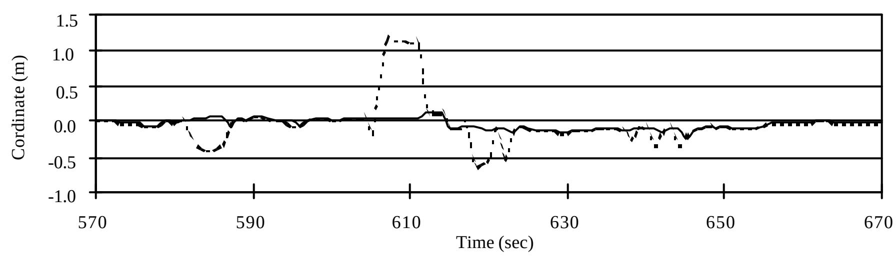

Fig. 5: Phenomenon one of sensor's failure

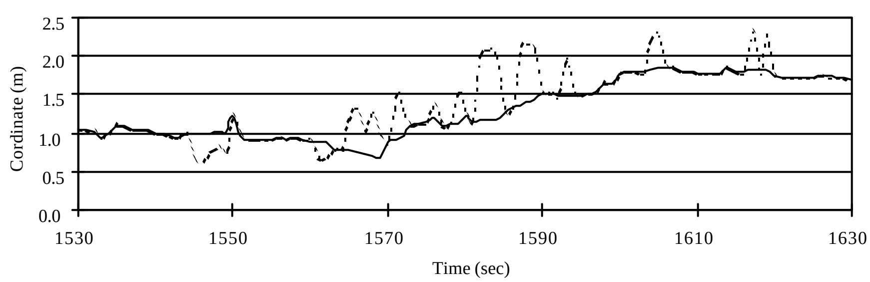

Fig. 6. Phenomenon two of sensor's failure

processing of environment and system information, abstracting and expressing of knowledge, associating and reasoning etc. It is a reflection of outside in underwater vehicles mind, recognition to the assignment and system which embodies the underwater vehicles self-determination and elaborative faculty. Commonly, the perception is regarded as upper intelligent behavior. Here it is treated as underwater vehicles cerebellum with quick reaction. Therefore, the fusion technology of perception layer presented in this study is for the motion control system and it perfects the system from three closely interrelated aspects such as environment danger, system performance and propeller status. It will enhance the underwater vehicles survival capability and control ability. Here, perception to environment danger embodies non-conditional reflection behavior of under-water vehicles; system performance perception is a kind recognition of itself, as well as a base for fault diagnosis; while propeller status perception belongs to both recognition category and fault diagnosis category which ensure that the underwater vehicle can take proper control mode when failure occurs and guarantee it's safety and task completion.

Figure 7 shows that an underwater vehicle operates in an obstacle space, where obstacle avoidance and trap escape should be carefully considered. A new method of obstacle avoidance based on balance point of motion is proposed, by which safe navigation of underwater vehicles can be achieved through the fusion of target, obstacle and control capacity information (Sun *et al*., 2013). At point A1 and A2, underwater vehicles comes into the stage of moving along obstacles and breaks away from obstacles at point B1 and B2. During the whole process of underwater vehicles movement, due to the distance between underwater vehicle and one obstacle is smaller than that between underwater vehicle and target, the underwater vehicle is completely under the control of the obstacle information. In the transverse direction, the underwater vehicle keeps a safe distance from the obstacle and heads along the obstacle. Because of an advance displacement of heading control compared with longitudinal control, the forward velocity can always be kept no zero which ensures the achievement of moving along obstacles. And moving along obstacles will ensure that the underwater vehicle can't finally deviate the target direction. This can be inferred from the figure and also it is illuminated that the trap problem won't occur.

Figure 8 is a simulative test when the bow-side thruster is in failure (a) The movement result when the underwater vehicle return from point (10,10) to point (0,0) with normal thrusters, (b) The result with normal control strategy when the bow-side thruster failed which shows that the heading angle of the underwater vehicle can't be adjusted correctly and there was a really big position bias

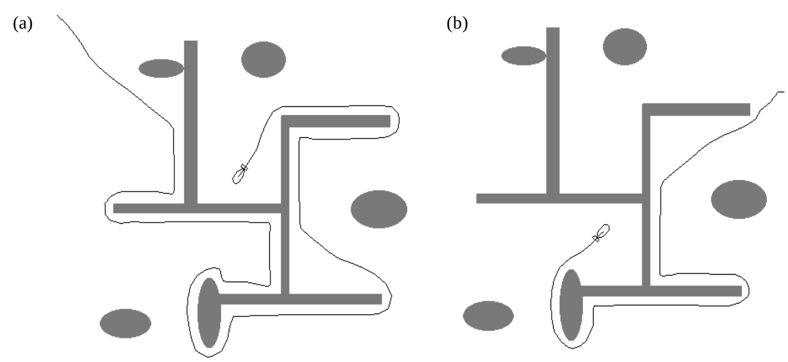

Fig. 7: Simulation of obstacle avoidance

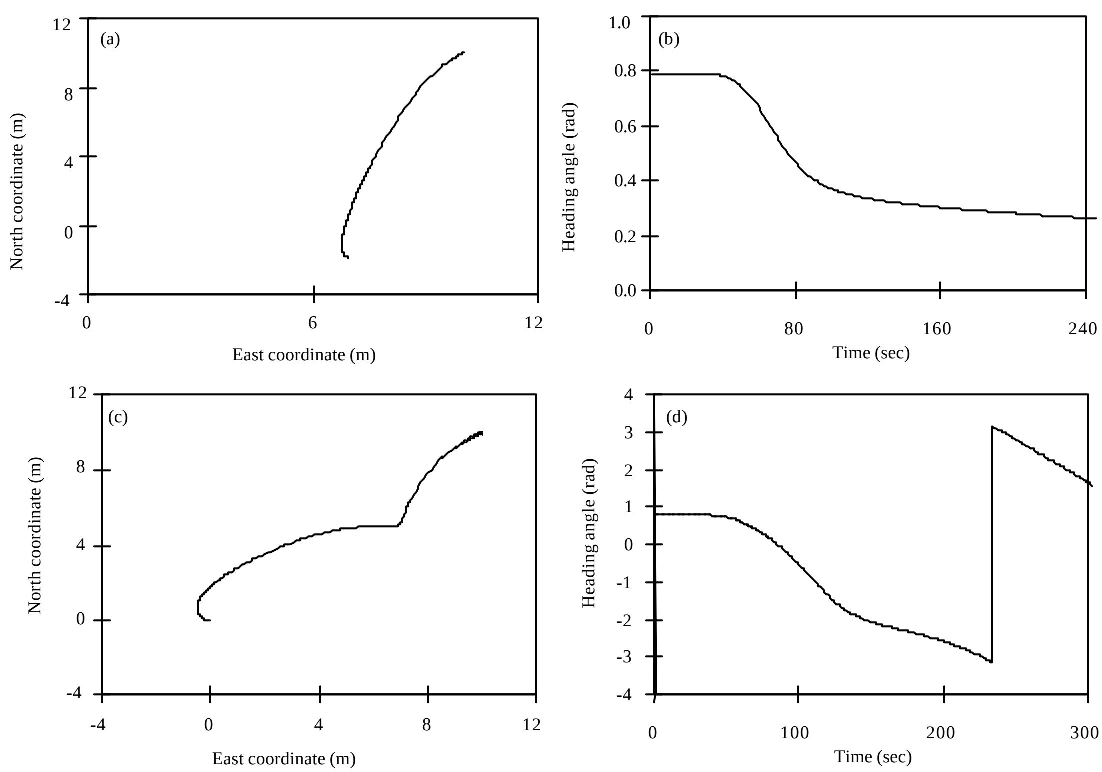

Fig. 8(a-c): Continue

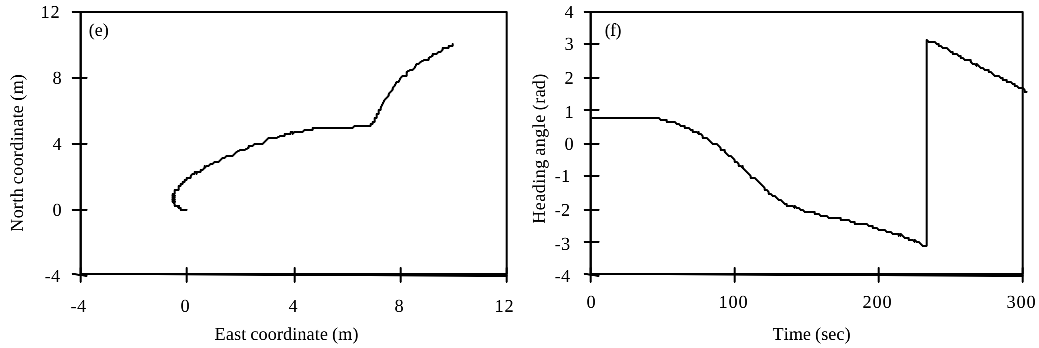

Fig. 8(a-c): Comparison result when bow-side thruster failed or not (a) Result when the thrusters are normal, (b) Bow-side thruster failed and control strategy was not changed and (c) Bow-side thruster failed and control strategy was changed

of east coordinate and (c) The result when control strategy is changed, where two main thrusters are used to control the longitudinal and heading bias. Under this strategy, the underwater vehicle is able to return the origin although it may move around the point for a while. This is because the underwater vehicle cannot control it's transverse movement. In order to eliminate the transverse's bias, it is quite necessary to adjust heading direction and keep itself pointing to the target. Then, the target can be reached through eliminating the longitudinal bias. According to the assumption that the heading angle varies from -180 to +180° in this study, the jump of angle at about 241 sec in Fig. c is only a normal change of angle. In fact, the movement is smooth.

CONCLUSION

According to the content above, it can obviously improve the control reliability and stability by applying information fusion technology to the motion control system of the underwater vehicle. For an underwater vehicle operating in an unknown environment, it is a very important for the underwater vehicle to successfully accomplish assignments that the underwater vehicle must be provided with some intelligent behaviors and a good controller which can be done with information fusion technology.

ACKNOWLEDGMENT

This study is supported by the National Natural Science Foundation of China (Grant No. 51209025, 51379026) and the China Postdoctoral Science Foundation (Grant No. 2013T60272) and Fundamental Research Funds for the Central Universities of China (Grant No. 3132013065, 3132013328).

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