Exploration of Backward Instructional Design in Inertial Navigation Algorithm

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Abstract. In terms of traditional curriculum design, it usually reaches the final learning goal through scattered knowledge points. The inertial navigation course has so many details, complex theories and formulas, whereas the traditional "teacher-oriented" approach to passing on knowledge points from the conditions will bring numerous inconveniences. Focusing on "learner-oriented" teaching, this paper takes attitude algorithm of strap-down inertial navigation as an example to demonstrate backward designs in teaching content with the purpose of achieving learning goals, so as to explore the effective way to improve the teaching effect of inertial navigation courses.

Keywords: curriculum design · backward design · attitude algorithm

1 Introduction

Inertial navigation is an essential branch in the field of navigation technology. With its characteristics of autonomy, stealth, real-time, immunity to geographical, temporal, and climatic conditions, and can output comprehensive motion parameters, it has become a widely used primary navigation method in the field of space, aviation, and navigation. It is one of the key technologies in modern military equipment. The Inertial Navigation course aims to show inertial navigation technology's principles, methods, and application techniques. Through this course, students will master the basic theory of inertial navigation and the design and analysis of navigation systems. Their ability to study and solve inertial navigation problems in related methods and engineering applications will be improved systematically. This course is in a core position in the whole curriculum.

The Inertial Navigation course has three main characteristics. First, there are loads of details and knowledge points, and each knowledge point is firmly connected. Second, each concept and knowledge point is highly theoretical, and the spatial imagination requirements are very high. Third, the needed formula is complex, with a complicated process to infer, and at the same time, it is precisely the basis for theoretical analysis. Thus, students have difficulties mastering this course's whole knowledge system and specific knowledge points. At present, most aspects of the curriculum are still "teacher-oriented," and the main body of teaching is still the teacher, which leads to the difference in teaching effect and teaching assessment due to the different background knowledge.

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In recent years, college and university education has advocated a "learned-oriented" teaching mode, emphasizing that the main subject of teaching activities is students, and the design of teaching objectives, teaching activities, and teaching assessments should be carried out around students [1]. The most crucial thing is how to put the "learner-oriented" concept into practice in teaching activities to promote the reform of teaching thinking, stimulate students' learning enthusiasm, improve their learning effect, and make them become the main body of the teaching process [2]. This paper attempts to reform the teaching content and methods of the Inertial Navigation course from the "learner-oriented" perspective and take the attitude algorithm curriculum as a pilot to make the backward design.

2 Learner-Centered Backward Design

In the course of giving lectures, the explanation of each teaching module is the process of solving problems. In the traditional teaching mode, students master loads of knowledge through condition-based systematic and meticulous explanations from front to back by their teachers. Such mono teaching mode makes students passively accept knowledge points, fail to grasp the context and logical relationships among knowledge points, and can only listen carefully to avoid the omission of any knowledge points. That is where the so-called cramming teaching comes from [2]. Not all learning goals are suitable for the conditions-based mode, which has shortcomings. For example, it is necessary to list all the known conditions for a particular problem during the solution course, but most known conditions are unhelpful to the solution and will confuse the public and affect final judgment.

The curriculum design focusing on reaching learning goals, also known as backward design, is put forward by the education teaching expert Grant Wiggins and Jay McTighe, based on reflection and innovation on traditional curriculum design [3]. They believe that effective curriculum design should be backward, which means that teachers backward infer knowledge from the expected result and the desired goal. Compared with traditional habitual thinking, it is a "reversed" logical timing and is also a results-oriented teaching process [4, 5]. The backward design takes students' learning effect as the basic springboard and reflects the main position of students in the teaching process. It takes the curriculum standards as the starting point and initial condition of logical thinking, determines what students should learn and master from the endpoint according to the learning goals set by the curriculum standards, and sets the appropriate assessment basis. The final and sophisticated educational program is formed by selecting the corresponding teaching method and knowledge point as well as the assessment of the achievement of the teaching goals [4, 6] (Fig. 1). The backward design incentives students to learn actively and turns the traditional teachers' educational goals into students' learning objectives on the basis of achieving learning goals. It is conducive to giving play to the prominent role of students and promoting their active learning. Meanwhile, teachers not only complete the transformation from "teacher-oriented" mode to learner-oriented" mode, but students can also strengthen their awareness of self-learning as the main body in the teaching process.

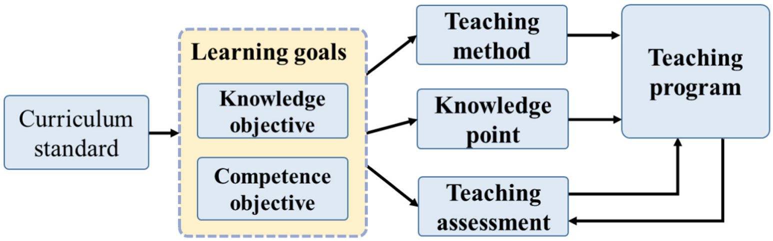

Fig. 1. Backward design

3 The Backward Design in the Attitude Algorithm

This paper takes the attitude algorithm in the strap-down inertial navigation algorithm as an example to illustrate how to perform backward design. The core task of inertial navigation (as shown in Fig. 2) is to calculate the required navigation parameters with the output of the inertial sensor, and the attitude algorithm is the most critical task of the strap-down inertial navigation algorithm. In IMU, the gyroscopes demonstrate the angular velocity relative to the inertial frame, and the accelerometers demonstrates specific force relative to the inertial frame. Such data are far from the final required navigation parameters, which need a complex transformation and arithmetic process. Considering different definitions of the inertial coordinate system, earth coordinate system, body coordinate system, geographic coordinate system, and other coordinate systems, as well as, complex inertial navigation mathematical models such as velocity differential equation, attitude differential equation, position differential equation, etc., the teaching method based on conditions is difficult for students to grasp the corresponding knowledge points and form a complete logical system. In the end, they will only know the knowledge itself but not why the knowledge is so, and some students do not even know it [7–9].

Backward design (Fig. 3) in teaching content of the inertial navigation algorithm can solve such a problem from the perspective of the teaching objective. The reverse flow chart of the attitude algorithm is shown in Fig. 4.

Students can be guided to think and learn backward in the following order in class:

The purpose of the attitude algorithm is to obtain a new attitude quaternion $\boldsymbol{q}_{k+1}$. According to the attitude quaternion updating formula $\boldsymbol{q}_{k+1} = \boldsymbol{q}_k \otimes \boldsymbol{r}_k$, in addition to the attitude quaternion $\boldsymbol{q}_k$ of the previous moment, the attitude updating quaternion $\boldsymbol{r}_k$

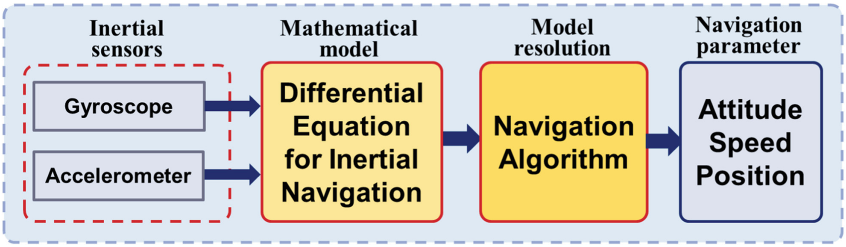

Fig. 2. The core task of inertial navigation

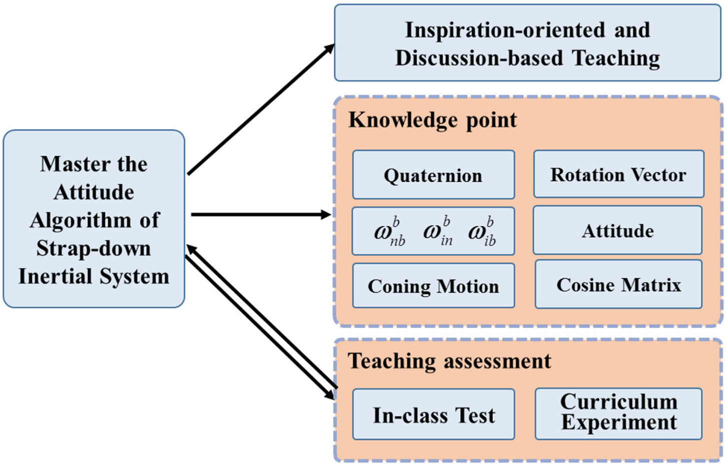

Fig. 3. Backward design of attitude algorithm

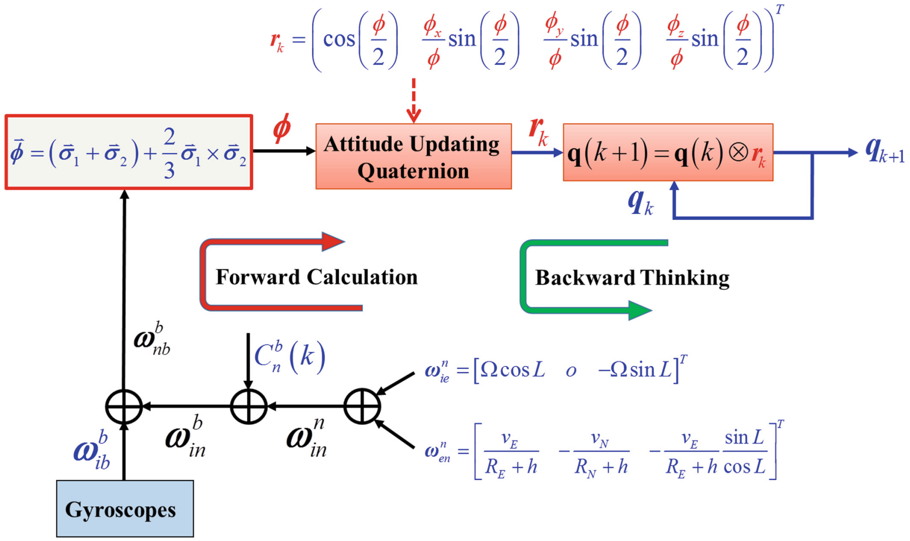

Fig. 4. Backward thinking flow chart of attitude algorithm

can be calculated. The computing procedure of the attitude differential equation shows that attitude updating quaternion has the following form:

$$r_k = \left(\cos\left(\frac{\sigma}{2}\right)\ \frac{\sigma_x}{\sigma}\sin\left(\frac{\sigma}{2}\right)\ \frac{\sigma_y}{\sigma}\sin\left(\frac{\sigma}{2}\right)\ \frac{\sigma_z}{\sigma}\sin\left(\frac{\sigma}{2}\right)\right)^T \tag{1}$$

where σ is the magnitude of the rotation vector $\vec{\sigma}$. The rotation vector $\vec{\sigma}$ can be figured out by directly integrating angular velocity if the carrier rotates in a fixed axis in the integral domain. In fact, during the computing process of continuous angular rate, the rotating axis of the rotating carrier will change over time. Therefore, the rotation vector cannot be obtained by simple integration, but it is needed to use the equivalent rotation vector $\vec{\boldsymbol{\phi}}$ to correct the error caused by non-fixed axis rotation. Changing the rotation vector in (1) into an equivalent rotation vector, the updating quaternion required in attitude updating can be obtained;

The problem now changes to the calculation of the equivalent rotation vector $\vec{\boldsymbol{\phi}}$. The correction of the equivalent rotation vector $\vec{\boldsymbol{\phi}}$ relative to the rotation vector $\vec{\boldsymbol{\sigma}}$ can be calculated by the multi-sample algorithm in the context of coning motion. The formula is as follows:

$$\vec{\boldsymbol{\phi}} = \left(\vec{\boldsymbol{\sigma}}_1 + \vec{\boldsymbol{\sigma}}_2\right) + \frac{2}{3}\vec{\boldsymbol{\sigma}}_1 \times \vec{\boldsymbol{\sigma}}_2 \tag{2}$$

where $\vec{\boldsymbol{\sigma}}_1$ and $\vec{\boldsymbol{\sigma}}_2$ are the normal rotation vectors corresponding to the two samples;

This step turns the problem of the attitude algorithm into the problem of the rotation vector. The rotation vector can be obtained by integrating the angular velocity $\boldsymbol{\omega}_{nb}^b$. In the time interval of a particular sample, the angular velocity $\boldsymbol{\omega}_{nb}^b$ can be seen as a constant. Now, the rotation vector will be calculated by the angular velocity $\boldsymbol{\omega}_{nb}^b$ multiplied by the time interval.

$\boldsymbol{\omega}_{nb}^b$ can be calculated by $\boldsymbol{\omega}_{ib}^b$, the output of gyroscopes and $\boldsymbol{\omega}_{in}^b$, the angular velocity:

$$\boldsymbol{\omega}_{nb}^b = \boldsymbol{\omega}_{ib}^b - \boldsymbol{\omega}_{in}^b \tag{3}$$

The angular velocity $\boldsymbol{\omega}_{in}^b$ can be figured out by the following formula:

$$\boldsymbol{\omega}_{in}^b = C_n^b(k)\boldsymbol{\omega}_{in}^n \tag{4}$$

Here, $C_n^b(k)$ is the corresponding direction cosine matrix of the previous attitude. Now, the angular velocity $\boldsymbol{\omega}_{in}^n$ is the final step to solve the question of attitude algorithm, and it can be calculated by the following formula:

$$\boldsymbol{\omega}_{in}^n = \boldsymbol{\omega}_{ie}^n + \boldsymbol{\omega}_{en}^n \tag{5}$$

The angular velocities $\boldsymbol{\omega}_{ie}^n$ and $\boldsymbol{\omega}_{en}^n$ have fixed forms. And now, all conditions that the attitude algorithm requires are confirmed by reversed inference.

This kind of solution which focuses on learning goals gives students a deeper understanding of the whole process and all parts of the attitude algorithm and improves their initiative to learn and explore. It is supposed that the traditional forward-thinking method is still used for the attitude algorithm. In that case, students may have more difficulties in the face of a wide variety of known conditions, and it is not easy for them to grasp the overall concepts of the attitude algorithms. This backward design can be extended to the explanation of each module of inertial navigation.

4 Assessment of Backward Teaching Effect

Teaching effect assessment is a key part of backward design. The setting of assessment focuses on whether the learning objectives are achieved, which can effectively correct the deviation of teaching objectives in the teaching process [10]. The assessment of the backward teaching effect needs to set up diversified assessment methods according to the specific course content. This paper designs the assessment of the teaching effect of the attitude algorithm (as shown in Table 1), which adopts the forms of Rain Classroom Quiz, questioning in class, assignments after class, and course experiments to examine the achievement of students' objectives in terms of knowledge and competence. The teaching effect of students in Navigation Engineering 2020 and 2021 was assessed, in which the students enrolled in 2020 adopted the forward-thinking method and 2021 adopted the backward-thinking method. The results show that after adopting the backward concept, students' learning effect has been improved effectively (Table 2), and either for knowledge or competence objectives, the percentage of those who were excellent and good was increased, while the percentage of those who were average and qualified was reduced.

Table 1. Assessment of Teaching Effect on Attitude Algorithm

Objectives Types	Learning objectives	Assessment
Knowledge objectives	1. Quaternion differential equation and its solution 2. Quaternion multiplication 3. Calculation of $\boldsymbol{\omega}_{nb}^{b}\boldsymbol{\omega}_{ib}^{b}\boldsymbol{\omega}_{in}^{b}$ 4. Definition of coning motion	Quiz: 1. First-order arithmetics of quaternion attitude recursion 2. Arithmetics of quaternion multiplication 3. Calculation of Attitude drift caused by coning motion 4. Review of $\boldsymbol{\omega}_{ie}^{n}\boldsymbol{\omega}_{en}^{n}$
Competence objectives	1. Know the process of attitude updating 2. Use the actual data to update the attitude of the inertial navigation system	Curriculum Experiments: 1. Achieve Matlab of attitude updating algorithm 2. Use attitude updating algorithm to deal with actual data

Table 2. The Comparison of Learning Effect in Attitude Updating of Navigation Engineering 2020 and 2021

Learning effect			Excellent (≥90 scores)	Good (80 ~ 89 scores)	Average (70 ~ 79 scores)	Fair (60 ~ 69 scores)	Unqualified (<60 scores)
Knowledge objectives	**2020 (17)**	Number	2	4	7	4	0
		Percentage	**11.8%**	**23.5%**	**41.2%**	**23.5%**	**0**
	2021 (24)	Number	5	9	7	3	0
		Percentage	**20.8%**	**37.5%**	**29.2%**	**12.5%**	**0**
Competence objectives	**2020 (17)**	Number	1	2	9	5	0
		Percentage	**5.9%**	**11.8%**	**52.9%**	**29.4%**	**0**
	2021 (24)	Number	4	8	9	4	0
		Percentage	**16.7%**	**33.3%**	**37.5%**	**16.7%**	**0**

5 Conclusion

It requires every educator to explore in practice on how to teach a good course and how to better impart knowledge to students. Backward design is the research result of Wiggins and McTighe in the context of American education. Thus, we must only copy it partially in our curriculum design but instead, we should learn from its concept that the backward solution method for achieving learning objectives is more suitable for solving problems with complex systems and known conditions. In teaching activities, more consideration can be given to this method to sort out and explain knowledge points to improve students' learning.

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