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Modular Intelligent Fixture Design for Bodywork of Electric Vehicles

Hamid Rezaei[1], Hamid Soleimanimehr[1,✉], Shahram Etemadi Haghighi[1], Morteza Shankayi[2], Javad Gholampour Darzi[3]

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ABSTRACT. A modular intelligent fixture is designed for bodywork of electric vehicles. An electromechanical system for the fixture is proposed and an intelligent algorithm to automate the car production is developed. In this system, the mechanism of movement is designed using an electric actuator and a transmission system including ball screw, bearings, slot and saddle movement system. This is particularly applied to the manufacturing of the bodywork of an electric vehicle. This application minimizes the time needed for fixture tools design and selection. An artificial intelligence code was developed for controlling the fixture system. The flexible system allows for simultaneous manufacturing of different bodyworks of electric vehicles.

Keywords: Bodywork fixture; Electric vehicles; Artificial intelligence.

INTRODUCTION

Almost in all production process, it is needed to use fixturing tools having vital rules in precision fabrication and reducing time production.[1] Dimensional and geometrical error of workpiece are so much important in new industries.[2, 3] So many parameters have to be investigated in designing a fixture tool such as dynamic force.[4] An electric vehicle uses a battery rather than an internal combustion engine as a motive force. Most companies are attempting to propose their electric vehicles due to the global tendency toward vehicle electrification. In designing these vehicles, batteries, and in some, the engine is built-in under the body. Therefore, the main-line of these vehicles' bodies differs from those in combustion engines. Their main-line is deeper than combustion engines because of the battery installment below the body, and they have a larger main-line in terms of height. Due to this difference in the bodywork design of electric vehicles, automotive companies need to design and manufacture a separate production line. Modular fixtures are produced via a combination of prefabricated parts and are widely used in production systems with high flexibility. The system based on the modular fixture is called the Modular Frame System (MFS). These fixtures are commonly used in Flexible Manufacturing System (FMS) and Computer Integrated Manufacturing System (CIMS) due to high flexibility.[5] Nee and Kumar developed an automated fixture design system for CAD software and expert system shell.[6] Ponder focused on automated fixtures design.[7] He developed his plan based on two criteria of stability and being fully constrained. Being fully constrained means eliminating all degrees of freedom of the workpiece.[7] Olaiz et al. examined the role of intelligent fixtures for fixing and preventing movement in a production process and requirements for intelligent adjustment of flexible fixtures during machining and succeeded in improving the manual inspection reduction parameters, automation of adjustment tasks, and enhancement of the machining operation.[8] Hamedi reached a smart method for designing the fixtures by combining the genetic algorithm with the neural network.[9] Zhang et al. proposed an optimal design and analysis for the location of fixtures using mathematical methods.[10] Armillota et al. investigated the way deviation on modular fixtures

✉ Corresponding author.
E-mail address: soleimanimehr@srbiau.ac.ir (H. Soleimanimehr)

[1] Department of Mechanical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

[2] Mechanical Engineering Department, Tarbiat Modares University, Tehran, Iran
[3] Mechanical Engineering Department, Tehran University, Tehran, Iran

propagate on location tolerance of holes' pattern.[11] According to an agreed principle, the position of each locator is represented by a Gaussian probability density function. The optimal position of the locators is considered by minimizing the deviation in whole sample positioning during drilling due to the inaccuracy of locators. Monavari et al. analyzed the connection torques on fixture vibration characteristics experimentally.[12] The shaker model, along with fixture, is analyzed selectively as two degrees of freedom model by considering frequencies and fixture modes. The optimal value for screw tightening torque was proposed by empirical results analysis. Morgan et al. examined the defective parts produced from vibration and led to proposing a solution related to fixture structure or contact surface between workpiece and system.[13] They suggested installing a nanostructure sensor on the intelligent fixture, and this improved the workpiece and reduced vibrations. Parviz et al. studied the fixture system design for parts with shape-free geometry.[14] In this research, an analytical method is introduced for the automated fixture system of these types of parts. The fixture system design is executed based on three principles, in which fixture application points are determined from the first two principles and verified from the third principle. The capability for automated fixture system design for parts and integration with other fixture design modules allows industrial uses of this system. Khodabandeh et al. examined the fixture's clamp layout optimization for sheet metal with initial variation based on the ant colony algorithm.[15] They studied the relation between initial plate deviation and the final product and proposed a method via the ant colony algorithm and finite-element capable of optimizing the position of clamping points aiming to reduce the product deviation and minimize the number of clamping points. The results show that reducing the fixture plate deviation decreases the product deviation after assembly. Gardyński et al. presented the results of research on the structure and strength of composite body elements of selected vehicles.[16] Undamaged components were examined by Kasza.[17] From the point of view of life and property protection, research and developed the lightning protection of electric vehicles. Rincón et al. introduced a reliable technique for chemical-metallographic tests of tempered marks on steel alloys of vehicle body.[18] Arsene et al. investigated wind drag resistance and its effect on the electricity supply required for vehicle movement.[19] Manea et al. have shown that simple spring-mass model is very useful in developing vehicle structures in the case of an impact.[20] Surbly et al. worked by processing data of laser sensors of distance measurement, investigated road roughness.[21]

This article proposes a solution for developing automatic fixtures using the computer. For this purpose, the development of an expert system is considered to plan modular fixtures. Determining the location of fasteners and fittings is another requirement of fixtures' design. In this expert system combination method, the pin clamp model in the workpiece kinematic is used to configure the fixture, which is an innovation.

MATERIALS AND METHODS

The Intellectualization and Expert System

Designing and proposing a flexible, intelligent fixture model for producing the bodywork main-line is very helpful in solving this issue. This flexible, intelligent fixture model allows changing coordination of units in three X, Y, and Z axes. By changing the coordinations in the Z-axis, altering the height becomes possible. Production of one or more bodywork models of both combustion and electric types becomes possible by introducing this intelligent, flexible fixture. This saves production costs, reduces the total product price, quickens the production process, and increases the accuracy of the manufactured product and variety of products. The fundamentals of fixture design can be proposed in the form of integrated and arranged methods. Following these methods and principles greatly helps in quicker training of new designers. The application of the computer and analytical methods to achieve the mentioned goals is increasing. Expert systems belong to artificial subset since its problem-solving is heuristic. In programs written in the algorithmic form, the input data is manipulated and passed to the next stage. While in heuristic programs, it reaches the goal via creative and trial-and-error methods according to the resources and searching in the state space.[8]

State Space

The state space is a space in which output states can be reached from the input states. For instance, the input state is the workpiece with 6 degrees of freedom in fixture design, and the output states are a combination of different states in which the workpiece is completely restrained. There might be some intermediate stages from initial states to final states. By increasing the intermediate states, the state space expands quickly. This excessive expansion is called the "information explosion." The state-space can be represented as a tree diagram. In that case, each state is called a node, and the solution pathway is considered a branch.

Regulations in Expert Systems

In expert systems, knowledge is shown as a set of laws. These regulations are stated as if {Condition(s)} then {Operation(s)}. This set of regulations are called a knowledge base. Indeed, there are other methods for creating a knowledge base (frames, semantic networks, logic).

Development of expert system

For developing an expert system, the below cycle needs to be considered as three fundamental steps:

1. Problem definition and determining whether it is proper for an expert system or not.
2. Production of the knowledge base
3. Error detection and regulations review

According to Fig. 1, the following processes need to be proceeded to produce a more comprehensive system:

1. Determining the functions needed to be performed by the system.
2. Determining the available knowledge.
3. Selecting an adequate mechanism for expression and inference
4. Defining the inference required for the summation of the components.
5. Components organization, if needed.
6. Production of the knowledge base.
7. Reviewing and correcting the knowledge and other system components, if needed.

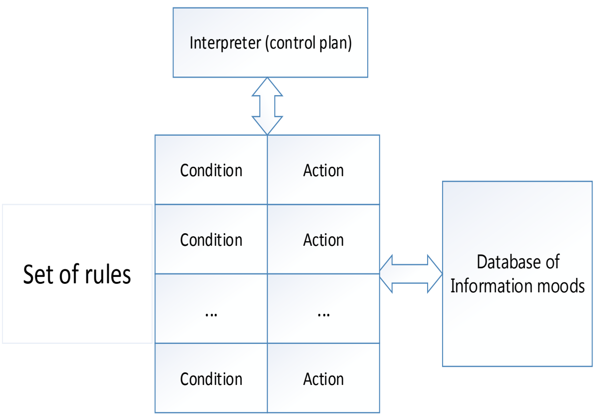

Fig. 1: Structure of an expert system.

Two datasets are utilized in the program. In these datasets, the input and output data are stored. The input data consists of a type, direction, and amount of machining force, type, direction, and finality of the plane. The output data will be the fixture type and validity of using it. A sample of the applied rule to the expert system program is as following:

```
(defrule 1
  if (finish surface is yes)
     (urgency fixture is no)
  then 1
     (identity fixture is no-fixturing))
```

The rules must be in four words. In this rule, the `surface` is a concept with an initial value of `finish`. `Identity` is the target value for `fixture` term. Number 1 is the rule number after `defrule`, and the number after `then` is the certainty value.

Inference Engine

In CAFD comprehensive system, a backward inference strategy is applied for the inference engine. This is due to being quicker, lower storage occupation, and user convenience. If there is no data in the program's dataset, the program first attempts to receive data from the user. If the user responds unknown, the program tries to discover the data using rules and inference. Fig. 2 represents the inference procedure in the expert system program.

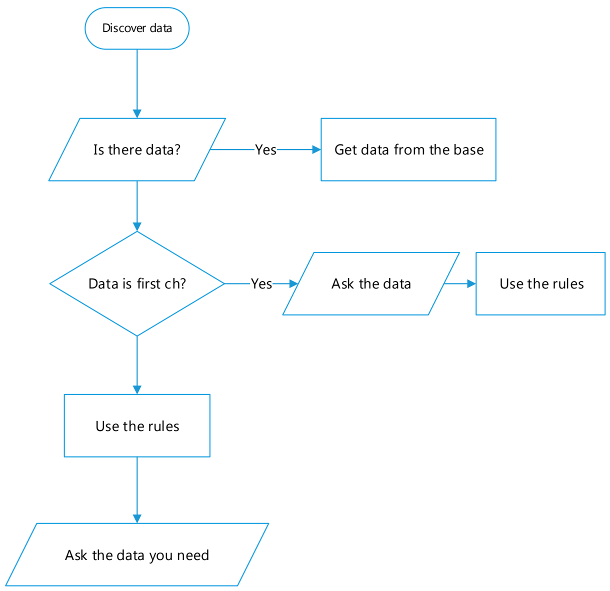

Fig. 2: Inference procedure of an expert system.

The program examines the rule contents first. If the required data and one of the rule contents do not match, it is rejected. For unrejected rules, other rule contents are investigated, and newer data is demanded if needed. By proving all contents, the rule certainty is combined with data, and the result is added to the list of obtained results.

RESULTS AND DISCUSSION

Design and Modeling of a Fixture Component

For verifying the results of the expert system, an output has been exported from that. In this mechanism, the movement is provided via an electric actuator (servo motor), and the evolution is converted into linear movement via a ball screw. The linear displacement is applied in three X, Y, and Z axes via rail, wagon, and other dependent parts.

First, the modeling of the fixture's bottom plane in sketch and part environment, and then the motion range of units were determined. For replacing the rails, their lower components that are holding ingots are to be modeled. The base parts of the rails were installed in the movement range of units to provide correct moving conditions of units. Afterward, assembly and placement of standard X-axis parts such as servo motor, servo motor phalange, ball screw, bearings, couplings, and others were performed in the assembly environment. For unit movement in X-axis, movement conditions need to be provided according to the predetermined mechanism design. The actuator of this movement is a servo motor which its rotational motion is converted to linear motion via a ball screw. A coupling pair is responsible for connecting the servo motor with a ball screw, and two bearings restrain both ends of the ball screw. The linear motion is transmitted to the pin clamp base plane via rail, wagon, and holding nut. In the end, after modeling the non-standard parts and assembly of these components along with standard parts in three X, Y, and Z axes, a unit was completed (Fig. 3).

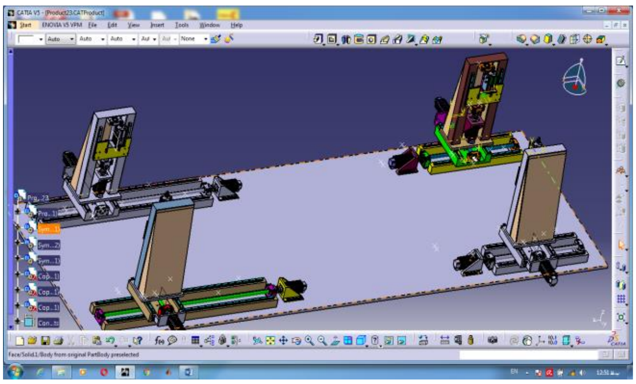

Fig. 3: Four completed units.

The other three units were not modeled and designed due to their similarity with the first one, and the designed unit was transmitted to the determined points in three other units via symmetry command. According to the new mechanism design, the motion in three X, Y, and Z axes of designed units became possible.

Fig. 4 represents the perspective view of intelligent, flexible fixtures in three modes.

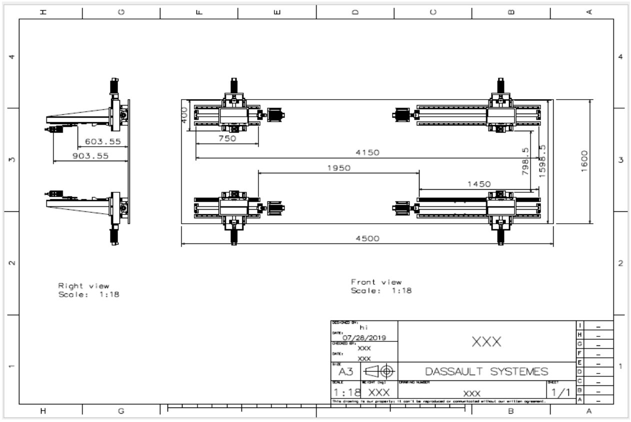

Fig. 4: The designed perspective map with three views.

By comparing the results of Fig. 4 with fixturing design principles, it can be shown that there is good agreement.

CONCLUSION

In this paper, a new model of intelligent, flexible fixtures is proposed to be used in electric and combustion engine production lines. This proposed model is a new generation with a different and acceptable performance of programmable, flexible fixtures. The configuration of units is performed well via an expert system. An artificial intelligence code was developed in MATLAB software and used for configuring the units. The results were completely satisfactory. This fixture model is capable of evaluating the applied fittings in the fixture from the following aspects. In terms of bodywork being fully restrained and effectivity of fitting in removing the degrees of freedom. Considering the motion of units in three X, Y, and Z axes and the capability of changing in the Z-axis, producing combustion engines and electric vehicles from one or multiple platforms in a production line becomes possible. This saves a lot of costs regarding design and manufacturing a new production line for electric bodywork in automotive companies. By noting the programmability of this fixture, IoT technology can be used in programming and controlling it in the future.

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