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Electronic Cam Motion Generation by Using Stepper Motors and Pinion Gears

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ABSTRACT

Electronic cam is a combination of a computer program for motion definition and a high-performance servo mechanism. In this study a new method for generating electronic cam motion is introduced. The proposed method, based on a Graphical User Interface (GUI), uses a stepper motor and a rack-pinion system. The proposed electronic cam allows the user to create any type of non-linear motion in setup limitations. The GUI offers to enter parameters of the stepper motor which will be used as an actuator, takes data of the cam from defined position, plots the basic graphs on cam-follower mechanism, gets parameters of the pinion gear converting the rotary motion into the linear motion, sets up the computer connection and runs the stepper motor in real time by using a PC's parallel port. Besides, it allows the user to animate both classical and proposed cam mechanisms. With this method, one can obtain a high-speed, reliable and application-oriented motion, just as obtained from a mechanical cam system.

Key Words: Electronic Cam, GUI, Programming, Stepper Motor, Pinion Gear.

1. INTRODUCTION

In various industrial applications, mechanical cams are used to create motion according to a particular profile, depending on a master axis position. However, this mechanical solution is very inflexible and can no longer cope with the requirements of modern production and processing machines. As a result, mechanical cam discs in system and mechanical engineering are increasingly being replaced by electronically controlled drives called electronic cams. The electronic cam is a technique used to perform nonlinear motion electronically similar to that achieved with mechanical cams. The electronic cam replaces the traditional mechanical cam with a servomotor and software programmable cam profile. Electronic-cam improves accuracy and repeatability. In electronic cam applications, the cam profile is not anymore given by a mechanical part specifically designed but by a user program. Consequently, modification of the cam profile is very easy and reduces time significantly. Therefore, many researches are done for this topic [1, 2, 3].

DC servo motors, having been used in contemporary electronic cams, are very suitable for complex motion tasks because the speed and torque in DC motors are easy to control by varying the voltage and current. But, due to the feedback characteristic, motion systems using this kind of motor are expensive and highly complex. This is one of the main reasons for using a stepper motor as an actuator in proposed electronic cam system when considering the trade-off of price and system performance.

A stepper motor is an electro-mechanical device which converts electrical pulses into discrete mechanical movements. One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. Its position is known simply by keeping track of the input step pulses. A stepper motor can be a good choice whenever controlled movement is required. They can be used to advantage in applications where rotation angle, speed, position and synchronism need to be controlled. Stepper motors have found their

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place in many different applications [4, 5]. Because of these inherent advantages, a stepper motor is chosen as an actuator for electronic cam motion generation in this study. There are three basic types of stepping motors: Variable-reluctance, Permanent magnet and Hybrid. The hybrid stepper motor combines the best features of both the permanent magnet and variable-reluctance type stepper motors. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with others. Hence, a hybrid stepper motor with two-phase is used in the experimental study.

In this paper a GUI (Graphical User Interface) driven from Matlab program has been developed for programming and controlling different types of stepper motors at different drive modes in order to realize electronic cam motions. The GUI is built with benefiting from the facilities offered by the Matlab programming language. Matlab implements GUIs through GUIDE (Graphical User Interface Development Environment). All kinds of stepper motors, having up to 8-separate-excitating signal and a unipolar winding configuration, can be programmable and controllable in real-time by using this software via parallel port of a PC. The developed GUI, taking only the distance-angle data of cam, is capable of realizing many different cam motions successfully. In order to perform cam motion, the proposed method uses a rack-pinion gear for converting the rotary motion of the stepper motor into the linear motion.

2. METHOD

Matlab is chosen as the basic programming tool primarily, because of simple GUIs, immediate graphics facilities, built-in functions, and the possibility of adding user-written functions, interactive mode of work, simple programming and its wide availability on various computing platforms. These factors make Matlab a powerful tool for research and practical problem solving. Matlab implements GUI through GUIDE. A GUI is a user interface program built with graphical objects such as buttons, text fields, sliders and menus. In fact, these definitions are well known for almost all computer users. Applications that provide GUIs are generally easier to learn and use since the person using the application does not need to know what commands are available or how to use them. GUIs assure the communication process between the user and the system's inference engine.

The parallel port of a PC is used to drive stepper motors by using the DB-25 parallel port connector. The PC's parallel port is a simple and inexpensive tool for building computer controlled devices and projects. It is an 8-bit bidirectional interface designed to transmit data synchronously using transistor-transistor-logic (TTL) signal level. TTL outputs can source 2.6 mA and sink 24 mA. Thus, small-size stepper motors can be driven from a PC's parallel port with a simple interface circuit containing a transistor. A computer connection with 8-line via parallel port is set up in this study. So, 8-different excitation signals can be taken from the PC. Almost all programming languages allow programmers to access parallel port using some library functions. Matlab program also has some useful library functions such as digitalio, addline, putvalue.

Animations of the classical and proposed cam mechanism in the main GUI window are carried out with computer graphics. Computer graphics are based on the fundamental linear transformation matrixes. Computer graphics is usually formed by rotating, translating, scaling and performing various projections on the data [6]. In animation of the classical cam motion, the cam profile is first formed with the data provided by the user, and a cam follower is sketched in proportion to the cam profile. The animation is realized by rotating the cam profile linearly and translating the cam follower suitably. In animation of the proposed method, the rack and pinion gear is first shaped with the parameters entered from the user; and a cam follower attached to the rack is drawn in proportion to the pinion. Parametric equations of the cycloid curves are used to constitute the gear profiles. Animation of the proposed method is realized by rotating the pinion gear appropriately and translating the rack and cam follower suitably.

3. AN OVERVIEW OF THE GUI

Basically, the developed GUI consists of two sets of programs. One set is responsible for controlling the stepper motor in order to realize electronic cam motions; and the other is responsible for animating the cam motions. The main GUI window, displaying the default values, is given in Figure 1. The main GUI window mainly consists of five frames (A, B, C, D, E).

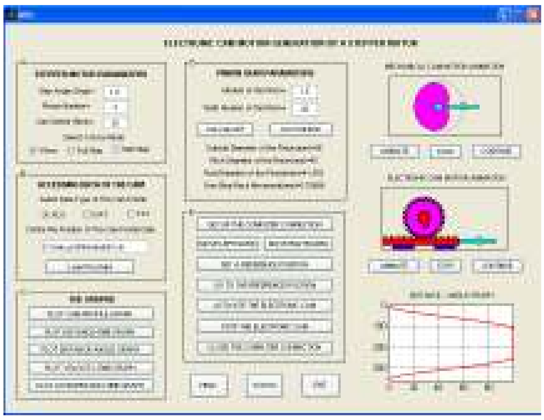


Figure 1. The main GUI window.

Frame-A is the part for inputting the stepper motor's parameters such as step angle, phase number and drive modes. Usually stepper motors have two phases, but three-and five-phase motors also exist. Cam speed parameter, related to the stepper motor parameters directly, is given in this frame also. According to the selected stepper motor type and drive modes (wave, full, half), the user must select a drive mode correctly at this stage. Otherwise, the excitation signals used to control the stepper motor will not be produced properly.

There are three common types of drive modes: Wave Drive, Full Step Drive, and Half Step Drive. In wave drive, only one winding is energized at any given time. For a unipolar motor with two phases given in Figure 2, the stator is energized according to the sequence A>B>A'>B' and the rotor steps in the direction of CW. In full step drive, two phases are energized at any given time.

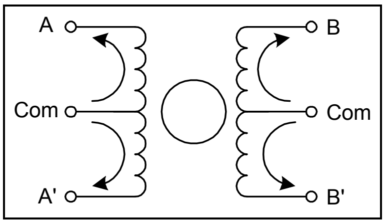


Figure 2. Winding configuration for a unipolar motor with two phases.

The stator is energized according to the sequence AB>A'B>A'B'>AB'. Full step mode results in the same angular movement as wave drive but the mechanical position is offset by one half of a full step. Half step drive combines both wave and full step drive modes. Every second step only one phase is energized; and during the other steps two phases are energized. This results in angular movements that are half of those in wave or full drive modes. Excitation sequences for different drive modes are given in Table 1. The rotating direction of stepper motors can be accomplished by reversing the step sequence.

Table 1. Excitation sequences for different drive modes.

	Wave				Full-Step				Half-Step							
Phase	1	2	3	4	1	2	3	4	1	2	3	4	5	6	7	8
A	○				○			○	○						○	○
B		○			○	○			○	○	○					
A'			○			○	○				○	○	○			
B'				○			○	○					○	○	○	

Frame-B is the part for accessing data of the cam. The developed GUI uses distance-angle data of the cam. In this frame, file type (.xls, .dat, .txt) and file position containing the cam data must be defined. The cam data must be structured in tabular form. The end point of the cam profile data should be the same as the starting point. A sample data file defined as a text-file in Notepad is given in Figure 3. The first and second columns represent angle and distance values respectively. The angle value should be given in degree and the distance in mm. By using the push button named with ‘LOAD THE DATA’, the user can introduce the cam data to the GUI. A sufficient amount of data should be provided to the GUI to get a good performance because the stepper motor rotates in discrete step increments. In general, to use a total of 361 data with an angle interval of 1° will be enough.

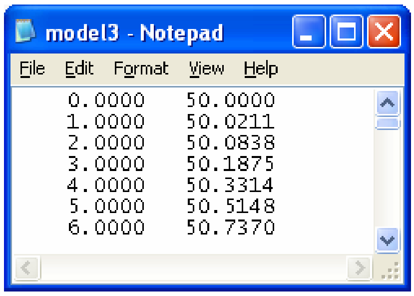
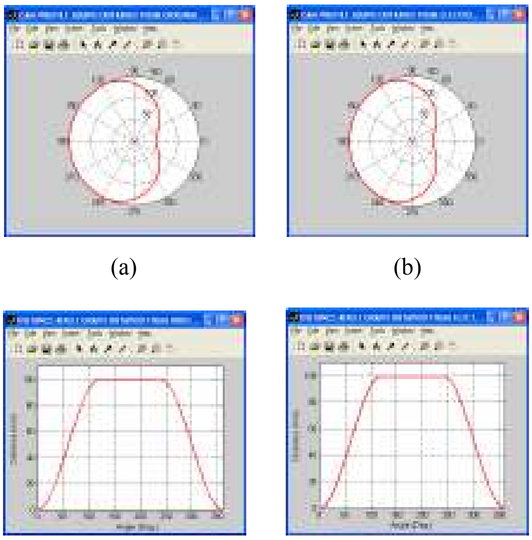


Figure 3. A sample data file.

Frame-C is the part for plotting the graphs including cam profile graph, distance-time graph, distance-angle graph, velocity-time graph and acceleration-time graph. All of the graphs in question can be plotted with push-buttons labeled with their own names. The push buttons displaying graphs employ the data loaded before. Cam profile graphs are formed in polar plot; and the rest are formed in 2D plot. Both velocity-time and acceleration-time graphs are constituted with derivatives of distance-time graph. Each push button displays two separate graphs; one of them belongs to the classical cam-follower mechanism; the other belongs to the proposed method. Some sample graphs are given in Figure 4. Figure 4.a,b show cam profiles obtained from original data and proposed electronic-cam motions respectively. Figure 4.c,d display distance-angle graphs of those. As seen from the figures, the results look very similar form, and there is no obvious difference. But, the difference between classical and proposed method come into existence when the graphs are zoomed in. Zoomed parts of the distance-angle graphs are given in Figure 5. According to these figures, while the classical method shown in Figure 5a varies smoothly, the proposed method shown in Figure 5b, c varies roughly. This arises from inherent running characteristic of stepper motors. Naturally, the smaller-step angle will have less ripples.

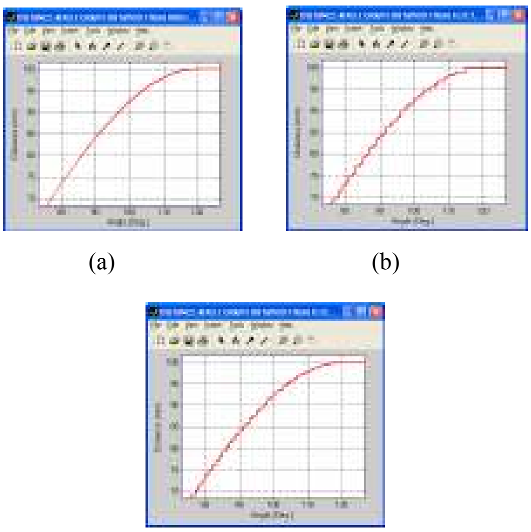
The rotary motion of a stepper motor can be converted into linear motion by several mechanical means. These include rack-pinion systems, screw-nut systems, ball screw-nut systems, chains, belt and pulleys and other mechanical linkages. The rack is a toothed bar or rod that can be thought of as a sector gear with an infinitely large radius of curvature. The pinion is driven by a motor so causing linear movement of the rack. While gearing is used to effect speed reduction and variance, screw-nut systems are often used to translate rotational movement into linear movement. The screw is normally driven by an electric actuator and the nut is fixed to one member of the mechanism. As the screw rotates the nut is driven linearly along axis of the screw, thus causing the member movement. Changing the direction of rotation reverses the direction of linear motion.

At this stage, the most effective and simple way to accomplish this conversion is to use a rack-pinion system. So, rotary motion of the stepper motor is converted into linear motion by using rack-pinion system in this work. The linear travel per step of the motor is determined by the motor's rotary step angle and the pitch-circle diameter of the pinion gear combination. The main disadvantage of this method is that the rack–pinion gear has a small amount of backlash. Actually, backlash is a general problem in gear systems. Backlash results from clearance between the gear teeth. It is evidenced by non-movement of the rack for an amount of time when the pinion changes direction.



(a) (b) (c) (d)

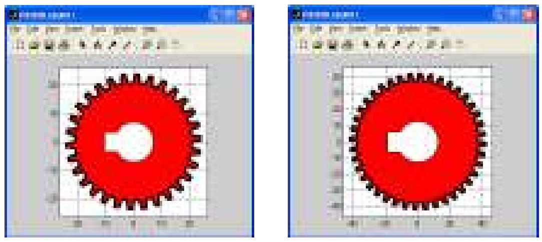
Figure 4. Sample graphs, a) Cam profile obtained from original data, b) Cam profile obtained from electronic cam motion, c) Distance-angle graph obtained from original data, d) Distance-angle graph obtained from electronic cam motion.



(a) (b) (c)

Figure 5. Zoomed parts of the distance-angle graphs obtained from, a) original data, b) electronic cam (a step angle of 1.8°), c) electronic cam (a step angle of 0.9°).

Frame-D is the part for inputting the pinion gear parameters such as module and teeth number of the pinion. In this frame some basic calculations about rack-pinion system are made and displayed. Thus, the GUI allows the user to choose different rack-pinion configurations in order to get a better one-step rack movement. In addition, figure of the pinion which is formed at actual dimensions parametrically can be obtainable by pressing the push button labeled with 'PLOT PINION'. Two sample figures of pinion gear are given in Figure 6.



(a) (b)

Figure 6. Pinion gear samples, a) Module=1.5, teeth number=30, b) Module=2, teeth number=40.

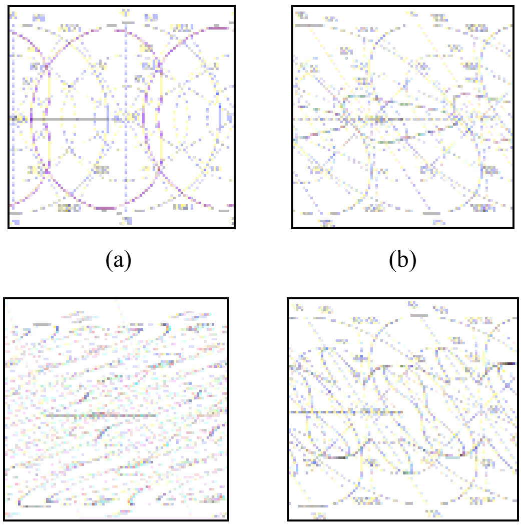
Frame-E is the part that the user carries out various tasks, such as setting up or closing the computer connection, running and stopping the electronic cam, setting a reference position and etc. To control the electronic cam, a computer connection must be first set up by using the related push button. The buttons labeled with 'MOVE LEFTWARD' and 'MOVE RIGHTWARD' move the rack to back and forward directions for positioning the follower to a reference position. The reference position where the electronic cam begins working can be any place in setup limitations. After setting a reference position with the related button, in any time the electronic cam can be positioned to the reference position by push-button named with 'GO TO THE REFERENCE POSITION'. The electronic cam can be activated by pressing the push button labeled with 'ACTIVATE THE ELECTRONIC CAM'. Electronic cam motion keeps going until pressing the push button named with 'STOP THE ELECTRONIC CAM'. Animations of the classical and proposed cam mechanisms and the distance-angle graph are given on the left side of the GUI window.

Nameplate data of the hybrid stepper motor used in the experimental study is given in Table 2. Loadless maximum speed of the motor is 15.7 rad/s (~150 rpm). The stepper motor can maintain a step angle accuracy within ±0.45° at half step drive, ±0.9° at wave and full step drive. The pinion having a module of 1.5, 30 teeth and the rack with a length of 30 cm are employed. The linear movement for one-step is calculated as 0.70686 mm for wave & full drive and 0.35343 mm for half drive modes in this design. These lengths are the most important numbers of the design because they determine the one-step linear accuracy of the system. If the accuracy is not enough for a particular application, naturally module of the pinion gear should be decreased, or a stepper motor with a smaller step angle should be employed.

Table 2. Nameplate data of the hybrid stepper motor.

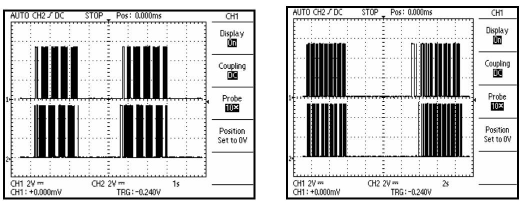
MARCA MINEBEA Co. Ltd – ASTROSYN, Stepper Motor, Type 23LM-C355-P6V	
Rated Current, Amps	1.5
Winding Resistance, Ohms	2.2
Inductance, mH	5.5
Holding Torque, Nm (Kg-Cm)	0.614 (6.2)
Detent Torque, Nm (g-Cm)	0.0540 (550)
Rotor Inertia, Kg-Cm2	0.110
Deg./Step	1.8
Steps/Rev.	200

Experimental setup has been tested for many cam profiles data obtained from cam design programs, and any type of non-linear motion has been realized successfully. Some tested cam profiles are given in Figure 7. Measurement results of two-excitating signal acquired from a digital oscilloscope for one-turn of cam are given in Figure 8. Excitating signals in Figure 8.a, b is employed to generate the cam motions given in Figure 7a, b respectively.



(a) (b) (c) (d)

Figure 7. Sample cam profiles, a, b) with one-dwell, c, d) without dwell.



(a) (b)

Figure 8. Measurement results of excitating signals of the stepper motor.

4. CONCLUSION

With the development of computer and servomechanics technology, electronic cams are becoming widely used. In this paper, a novel method for realizing electronic cam motions has been introduced. Contemporary methods use servo motors in order to perform cam motions. The introduced method, however, uses a stepper motor and a rack-pinion gear. For this purpose a GUI, based on Matlab program, has been developed. The GUI is explained in detail within the paper. Experimental setup is tested for many different cam profiles, and good results are obtained. The results show that the proposed electronic cam is very useful and flexible as much as its counterparts.

Although the proposed method has a very small amount of position error resulting from the stepper motor's running characteristic, it is relatively simpler and cheaper than its counterparts. So, it can be preferred for some applications for which small position errors are not important. The GUI controls the electronic cam in real time corresponding to the cam speed parameter given in the GUI window. However, this control strategy may not be suitable for some cam applications. In this case, proper sensors should be added to the system.

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