

MINIATURIZED HYBRID FEEDBACK CONTROL METHOD AND SYSTEM

Field of the Invention

This invention relates to a feedback control system. More particularly, this invention relates to a motion control system having a magnetic encoder and an optical encoder for a miniature multi-axes drive train. Still more particularly, this invention relates to a hybrid feedback compact arrangement including magnetic encoder and optical encoder.

Prior Art

Traditionally, optical encoders are used with motors for motion control feedback. These optical encoders suffer from the drawback of being larger in size and difficulty in miniaturization. Recently, use of magnetic encoders for feedback has become more popular for motion control feedback for small motors for two reasons. First, magnetic encoders are available in smaller sizes. Secondly, magnetic encoders offer greater precision than optical encoders for very small size encoders. It has become a trend nowadays that manufacturers attach magnetic encoder instead of optical encoders for small motors.

A magnetic encoder consists of a rotating gear made of ferrous metal and a magnetic pick-up that contains a permanent magnet and the sensing element. The gear, which is mounted on the rotating shaft, has precisely machined teeth that provide the code pattern. As the disk rotates, these teeth disturb the magnetic flux emitted by the permanent magnet, causing the flux field to expand and collapse. These changes in the field are sensed by the sensing element, which generates a corresponding digital or pulse signal output. The use of magnetic encoder typically creates a magnetic field which may interact with any nearby magnetic fields. This magnetic interference is undesirable and

will interfere with other nearby magnetic fields from other magnetic encoders or DC motors in the vicinity. However, tests reveal that while magnetic encoders perform consistently and accurately at normal and slow speeds, they lack the precision of optical encoders for position measurements at extreme high speeds.

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Thus, those skilled in the art are constantly striving to design an improved motion control feedback that works for a miniature drive system for moving an object.

Summary of the Invention

10 The above and other problems are solved and an advance in the art is made by a motion control system installed on a driver assembly for moving an object in accordance with this invention. A first advantage of a motion control system in accordance with this invention is that the motion control system is in a highly compact arrangement. Hence, it can be applied in precision engineering and/or surgical robotic arenas where miniature
15 components are required. A second advantage of a motion control system in accordance with this invention is that the motion control system produces minimum magnetic interference that may affect other adjacent devices. A third advantage of a motion control system in accordance with this invention is that the motion control system incorporates both optical and magnetic encoders being arranged in a certain configuration that can be
20 implemented in a compact space. A fourth advantage of a motion control system in accordance with this invention is that the motion control system caters for the designs of highly precise and compact robotic end-effectors which may have potential applications in precision engineering and surgical robotic fields. Further, the motion control system in accordance with this invention offers supreme solution that fulfils the needs of highly
25 compact multi-axes driving system.

In accordance with an aspect of the invention, a motion control system for a drive train configured in the following manner. The motion control system includes a magnet holder, a magnetic encoder and an optical encoder. The magnet holder has a first open end and a second open end. The first open end is coupled to a shaft of the drive train and the second open end has a cavity. The magnetic encoder includes a magnet secured in the cavity and a sensing element position apart from the magnet and facing the second open end. The optical encoder includes a light emitting element and a sensing element position apart from the magnet holder and facing a surface defined between the first and second open ends. The surface of the magnet holder includes a number of markings.

In accordance with an embodiment of the invention, the magnet is a permanent axial magnet having a north pole and a south pole. Further, the permanent axial magnet is secured in the cavity such that a portion of the north and south poles of the permanent axial magnet are being exposed and facing the sensing element of the magnetic encoder. Still further, the permanent axial magnet has a longitudinal axis running through the north pole and the south pole, the magnet holder and the sensing element of the magnetic encoder share a longitudinal axis that is perpendicular to the longitudinal axis of the permanent axial magnet. Preferably, a portion of the cavity is adapted to mate with a portion of the permanent axial magnet.

In accordance with an embodiment of the invention, each of the number of markings is parallel to one another. Preferably, each of the number of markings extends between the first and second open ends.

In accordance with an embodiment of the invention, the motion control system is implemented on a picomouse or micromouse.

In accordance with another aspect of the invention, a moving object is provided in the following manner. The moving object includes a base, a first driver, a second driver, a first motion control system, a second motion control system, and a controller. The first driver is arranged on a first side of the base. The first driver includes a first wheel, a second wheel, a motor, and a gear assembly connecting the motor to the first and second wheels. The second driver is identical to the first driver and arranged on a second side of the base. The first motion control system is coupled to a shaft of the first wheel of the first driver. The second motion control system is coupled to a shaft of the first wheel of the second driver. The controller controls a movement of the moving object. The first motion control system provides a feedback of the first driver to the controller and the second motion control system provides a feedback of the second driver to the controller.

Brief Description of the Drawings

The above and other features and advantages in accordance with this invention are described in the following detailed description and are shown in the following drawings:

Figure 1 illustrating a perspective view of a motion control system in accordance with an embodiment of this invention;

Figure 2 illustrating a top view of a moving object having two motion control systems in accordance with an embodiment of this invention;

Figure 3 illustrating an exploded view the motion control system in accordance with an embodiment of this invention;

Figure 4 illustrating a magnet and its magnetic field in accordance with an embodiment of this invention;

Figure 5 illustrating a first arrangement of the magnet to a magnet holder in accordance with an embodiment of this invention;

Figure 6 illustrating a second arrangement of the magnet to the magnet holder in accordance with an embodiment of this invention; and

Figure 7 illustrating a working prototype that has been implemented with the motion control system in accordance with an embodiment of this invention.

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Detailed Description

This invention relates to a feedback control system. More particularly, this invention relates to a motion control system having a magnetic encoder and an optical
10 encoder for a miniature multi-axes drive train. Still more particularly, this invention relates to a hybrid feedback compact arrangement including magnetic encoder and optical encoder.

Figure 1 shows a perspective view of a motion control system 100. Motion control
15 system 100 includes an optical encoder 110, a magnetic encoder 120 and a magnet holder 130. The magnet holder 130 is coupled to a gear assembly driven by a motor via a shaft 150.

Briefly, as the motor drives the gear assembly, magnet holder 130 rotates in
20 tandem with the shaft 150. As the magnet holder 130 rotates, the magnet secured in the magnet holder 130 also rotates and generate a rotating magnetic flux. The magnetic encoder 120 reads the rotating magnetic flux. Concurrently, the markings on the surface of the magnet holder will disturb the lights emitted by the optical encoder 110 and in turn generate optical signal for the optical encoder 110. This arrangement of both optical and
25 magnetic encoders 110 and 120 allows both optical and magnetic encoders 110 and 120 to be implemented in a small confined space. Further details of the motion control system 100 will be described below.

Figure 2 shows a top view of an embodiment of two motion control systems 100 being implemented on a moving object 200. Moving object 200 is a four wheels multi-axes control miniature vehicle. Moving object 200 may be a micromouse or a picomouse.

5 Moving object 200 includes a base 210, two sets of drivers 260L and 260R, a controller 280, and two sets of motion control systems 100.

Base 210 is a platform for holding various components of the moving object 200 together. Base 210 includes a left side, a right side, a front side and a rear side. A
10 Printed Circuit Board (PCB) may be provided above the base 210 to communicatively connect various components of the moving object 200. One skilled in the art will recognise that base 210 may itself be a PCB without departing from the invention.

Two drivers 260L and 260R are provided to moving object 200. A first driver 260L
15 is arranged on a left side of the moving object 200 while the other driver 260R is arranged on the right side of the moving object 100. Each of the drivers 260L and 260R includes a motor 261, a gear system 265, a front wheel 262 and a rear wheel 263. A battery 270 is provided on the base 210 for driving the motor 261. Motor 261 translates electricity from battery 270 to kinetic energy for driving the gear system 265 which in turn moves the front
20 and rear wheels 262 and 263.

The gear system 265 includes a number of meshing gears interconnecting each other to transmit rotational motion to the front and rear wheels 262 and 263 to drive the moving object 200 forward or backward. One skilled in the art will recognise that many
25 types of configuration of the gear system may be implemented without departing from the invention. Hence, for brevity, the exact configuration of the gear system 265 is omitted.

Controller 280 may be a microcontroller or a microprocessor. More particularly, controller 280 is a processing device for controlling the motors 261, receiving feedback signals from the motion control systems 100. One skilled in the art will recognise that the controller 280 may also perform other functions of moving object 200 without departing
5 from the invention.

Two motion control systems 100 are provided to moving object 100. One motion control system 100 is arranged on the moving object 200 to provide a feedback of the first driver 260L. In particular, the motion control system 100 is coupled to the shaft 150 of the
10 rear wheel 263 of the first driver 260L. The other motion control system 100 is arranged on the moving object 200 to provide of the second driver 260R. In particular, the motion control system 100 is coupled to the shaft 150 of the rear wheel 263 of the second drive 260R. One skilled in the art will recognise that the motion control systems 100 may alternatively be arranged to provide a feedback by coupling to a shaft of the front wheel
15 without departing from the invention. More details of the motion control system 100 will be described below with reference to figure 3.

Figure 3 illustrates an exploded view of the motion control system 100. Magnet holder 130 may be a rod or tube having two open ends 350 and 355. A first end 355 of
20 the base element connects to the shaft 150 of the rear wheel 263. The second open end 350 has a surface defining a cavity 310 for receiving magnet 320. One skilled in the art will recognise that the dimension of the cavity is dependent on the shape of the magnet 320. Hence, although figure 3 shows that the perimeter of the cavity 310 is rectangular in shape, one skilled in the art will recognise that other geometry may be implemented
25 without departing from the invention as long as the magnet 320 can be secured to the magnet holder 310. More details of the cavity 310 and the magnet 320 will be described below with reference to figures 5 and 6.

Each of the first and second open ends 355 and 350 defines a perimeter. In figure 3, magnet holder is shape of a tube having circular cross section. Hence, the perimeter of the first and second open ends is circular in shape. One skilled in the art will recognise that geometries other than circular may be implemented without departing from the invention. However, when implemented to the moving object 200, the magnet holder 130 is ideally circular in cross section so that lights diffracted by the markings 330 on the magnet holder 130 can be read by the optical encoder 110.

A surface is defined between each of the perimeters of the first and second open ends. Markings 330 are provided on the surface. Markings 330 are diffraction grating lines. The markings 330 on the surface of the magnet holder will diffract the lights emitted by the optical encoder 110. In turn, the optical encoder 110 generates optical signal based diffraction of the lights. One skilled in the art will recognise that although the markings 330 are straight lines extending between the first and second open ends and are parallel to each other, other types of markings may also be implemented without departing from the invention as long as each of the markings 330 are parallel to one another.

The magnetic encoder 120 includes a sensing element for reading the magnetic field. Sensing element of magnetic encoder is any sensing device that will detect the changes in magnetic field and in turn allow magnetic encoder 120 to generate a corresponding signal and transmit the signal to the controller 280. Magnetic encoder 120 performs as a feedback to monitor the movement of the gear systems 260L and 260R. The magnetic encoder 120 is arranged with the sensing element facing the second open end of the magnet holder 130. More particularly, the sensing element of the magnetic

encoder 120 faces the magnet 320 secured to the cavity 310 in order to measure the magnetic field.

The optical encoder 110 includes a light emitting element for emitting light onto the surface of the magnet holder 130, and a sensing element for reading the diffraction caused by the markings 330 on the surface of the magnet holder 130. As the light emitting element and the sensing element are fixed on the optical encoder 110, the magnet holder 130 is ideally circular in cross section so that lights emitted by the light emitting element can be directed onto the surface of the magnet holder such that diffraction caused by the markings 330 on the magnet holder 130 can be read by the sensing element of the optical encoder 110.

Lines 395 and 390 show the X and Y axes of the magnet holder 130 respectively. As shown in figure 2, a longitudinal axis of the shaft 150 is aligned with the X axis 395 of the magnet holder 130. Further, the cavity 310 is defined at the central area of the surface of the second open end 350. With the longitudinal axis of the shaft 150, X axis of the magnet holder 130 and cavity 310 being aligned and sharing the same axis, rotation of the rear wheel in the direction of the arrow 398 causes the magnet holder 130 to rotate in the same direction. Since the cavity 310 is defined in the central area, the changes in magnetic field in the region between the second open end and the magnetic encoder 120 read by the magnetic encoder 120 will be more accurate. If the cavity 310 is not defined in the central area of the surface of the second open end 350 but near the perimeter of the second open end 350, the changes in the magnetic field between the second open end and the magnetic encoder 120 will likely be irregular and the reading of the magnetic encoder 120 will likely not be consistent and in turn the feedback signals transmitted to the controller will not be useful.

The optical encoder 110, magnetic encoder 120 and magnet holder 130 are arranged such that all three components can be implemented compactly. In particular, the optical encoder 110 is arranged along the Y axis 390 which is 90 degrees from the X axis 395. In this arrangement, both optical encoder 110 and magnetic encoder 120 can be arranged in a compact space.

Figure 4 shows a cross section of magnet 320. Magnet 320 is a conventional miniature axial magnet having a north pole 410 and a south pole 420. Magnet 320 is a disk shape magnet. Lines 430 illustrate the magnetic field of magnet 320. Magnet 320 has a longitudinal axis 440 running through the north and south poles.

Figure 5 illustrates a method of arranging magnet 320 to cavity 310 of magnet holder 130 where the longitudinal axis 440 and X axis 295 are aligned. Markings 330 are omitted from figure 5 in order to show the arrangement of the magnet 320 and the cavity 310 clearly. In figure 5, cavity 310 is circular in shape in order to fit magnet 320. Direction 510 shows the rotation of magnet holder 130. Lines 520 illustrate the magnetic field of the magnet 320. As shown in figure 5, the magnetic fields are extending out of the magnet holder 130 and towards the sensing element of magnetic encoder 120. This arrangement of magnet 320 being secured to cavity 310 creates a large magnetic field which may interact with any nearby magnetic fields. This magnetic interference is undesirable and may interfere with other nearby magnetic fields from other magnetic encoders or DC motors in the vicinity. Although undesirable, the motion control system 100 would still work with this arrangement of magnet 320 in cavity 310 of magnet holder 130.

Figure 6 illustrates an embodiment of this invention where the longitudinal axis 440 of magnet 320 is arranged perpendicularly to the X axis 295 of magnetic holder 130.

More particularly, the longitudinal axis 440 of the magnet 320 is 90 degrees apart from the X axis 295 of magnetic holder 130. As shown in figure 6, a portion of both north pole 410 and south pole 420 of the magnet 320 are exposed and facing the sensing element of magnetic encoder 120. More particularly, a portion of the circular edge of the magnet 320 consisting of both north and south poles of the magnet 320 is exposed and facing the sensing element of magnetic encoder 120. This gives a high concentration of magnetic field, shown as lines 620, towards the sensing element of magnetic encoder 120. Magnetic fields away from the magnetic holder 130 in other directions are weak and therefore cause little cross magnetic interference to other nearby magnetic fields. This greatly improves and provides accurate feedback to the controller 260. Further, a feasible compact and miniature motion control having both optical encoder and magnetic encoder feedback system with very low cross magnetic interference is achieved. One skilled in the art will recognise that the longitudinal axis 440 of magnet 320 may also be arranged at an angle between 70° to 110° to the X axis 295 of magnetic holder 130 without departing from the invention as long as a portion of both north and south poles are facing the sensing element of magnetic encoder 120.

Intensive testing reveals that while magnetic encoders perform consistently and accurately at normal and slow speeds, they lack the precision of optical encoders for position measurements at extreme high speeds (approximately 3000 mm/s and above for micromouse robots). At extreme high speeds, some magnetic lines may be missed and not captured by the magnetic encoders, resulting in inaccuracy in position measurements. Fortunately, velocity measurements remain accurate due to consistency in the errors in the position measurements at extreme high speeds. The inaccuracy of the position measurements at high speeds may be compensated by scaling but the amount of scaling depends on the speed of rotation at extreme speeds. One possible solution is to use optical encoders for feedback control. However, optical encoders that can give the same

accuracy as the miniature magnetic encoders are large in size and therefore are too big to be fitted onto miniature structures. On the other hand, optical encoders that are miniature in size have very low resolution and their resolutions are too low to provide accurate and useful feedback for velocity and acceleration measurements. Currently,
5 miniature optical encoders have resolution of 32 lines per revolution while miniature magnetic encoders have resolution of 256 lines per revolution. If only optical encoders are used, the accuracy for speed and acceleration measurements would be very low. As speed is the change in distance over the time taken, and acceleration is obtained by calculating the change in speed over the time taken, if the position measurement is of
10 limited accuracy, the first order (i.e. speed) and second order (i.e. acceleration) changes will have far less accuracy. Hence, using optical encoder will therefore be unable to provide accuracy in speed and acceleration measurements at all speeds.

In the motion control system 100, the use of both optical encoder 110 and magnetic
15 encoder 120 provide reliable redundancy feedback control and precision control at high speed. While a single optical encoder or a single magnetic encoder is sufficient for motors running at normal speeds, such combination of optical encoder and magnetic encoder is highly useful for running motors at high speeds. In particular, the motion control system not only solves the inaccuracy of the magnetic encoders at extreme
20 speeds, it also provides redundancy control. Moreover, the method illustrates a compact way to achieve redundancy control and precision control at high speed.

The use of optical encoder provides position control as optical encoder offers reliable position feedback. When implemented on the moving object 200, the optical
25 encoder tracks its vector position and coordinates more accurately than using magnetic encoder alone which tends to miss some magnetic flux lines at high speed. Feedback from magnetic encoder are used for speed and acceleration control as they provide

reliable and accurate measurements. Missing magnetic lines do not have significant effect on accuracy of speed and acceleration measurements. Magnetic lines represent lines in final position will cancel out the missed magnetic lines in initial position for velocity calculations, resulting in accurate velocity values. Acceleration can be calculated accurately from the accurate velocity values. In brief, the optical encoder provides position control while the magnetic encoder provides acceleration control.

Figure 7 shows a prototype that has been developed and tested successfully. The combined magnetic encoder and optical feedback method with ultra-low cross magnetic interference has been implemented successfully in four-wheel two-axes picomouse robot. The low cross magnetic interference from the magnetic encoder units allows the direct current motors to be driven at their top performance without any problems. The optical encoder feedback allows high precision and accurate position control at extreme high speeds.

The above is a description of exemplary embodiments of a motion control system in accordance with this invention. It is foreseeable that those skilled in the art can and will design alternative systems based on this disclosure that infringe upon this invention as set forth in the following claims.

Claims:

1. A four wheel moving object comprising:

a base having a first side, a second side, a front side and a rear side;

5 a first driver arranged on said first side of said base having a first wheel, a second wheel, a motor and a gear assembly connecting said motor to said first and second wheels;

a second driver arranged on said second side of said base, said second driver identical to said first driver;

10 a first motion control system comprising:

a magnet holder having a first open end, a second open end and a surface defined between said first and second open ends, said first open end being coupled to a shaft of said first wheel of said first driver and said second open end having a cavity, said surface having a plurality of markings;

15 a magnetic encoder including:

a disk shaped permanent axial magnet having a first end, a second end and a continuous sidewall between said first end and second end, said disk shaped permanent axial magnet is bisected between said first end and said second end such that said continuous sidewall consists of a north pole and a south pole, said disk shaped permanent axial magnet being secured in said cavity;

20 a magnetic sensing element position apart from said disk shaped permanent axial magnet and facing said second open end, wherein said magnet holder and said magnetic sensing element share a longitudinal axis, and said permanent axial magnet has a longitudinal axis running through said north pole and said south pole that is arranged at an angle between 70 to 110 with respect to said longitudinal axis of said magnet holder and said sensing element;

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an optical encoder including a light emitting element and a light sensing element position apart from said magnet holder and facing said plurality of markings; and

a controller for controlling a movement of said moving object and communicatively
5 connected to said first motion control system to receive a feedback from said first motion control system.

2. The four wheel moving object according to claim 1, wherein said magnet holder and said sensing element of said magnetic encoder share a longitudinal axis that is
10 perpendicular to said longitudinal axis of said permanent axial magnet.

3. The four wheel moving object according to claim 1 wherein a portion of said cavity is adapted to mate with a portion of said permanent axial magnet.

15 4. The four wheel moving object according to claim 1 wherein each of said plurality of markings are parallel to one another.

5. The four wheel moving object according to claim 4 wherein each of said plurality of markings extends between the first and second open ends.

20 6. The four wheel moving object according to claim 1 wherein said plurality of markings are diffraction grating lines.

7. The four wheel moving object according to claim 1 further comprising a second
25 motion control system comprising:

a magnet holder having a first open end, a second open end and a surface defined between said first and second open ends, said first open end being coupled to a

shaft of said first wheel of said second driver and said second open end having a cavity,
said surface having a plurality of markings;

a magnetic encoder including:

a disk shaped permanent axial magnet having a first end, a second end
5 and a continuous sidewall between said first end and second end, said disk
shaped permanent axial magnet is bisected between said first end and said
second end such that said continuous sidewall consists of a north pole and a
south pole, said disk shaped permanent axial magnet being secured in said cavity;

a magnetic sensing element position apart from said disk shaped
10 permanent axial magnet and facing said second open end, wherein said magnet
holder and said magnetic sensing element share a longitudinal axis, and said
permanent axial magnet has a longitudinal axis running through said north pole
and said south pole that is arranged at an angle between 70 to 110 with respect to
said longitudinal axis of said magnet holder and said sensing element;

15 an optical encoder including a light emitting element and a light sensing element
position apart from said magnet holder and facing said plurality of markings.

8. The four wheel moving object according to claim 7 wherein said base is a printed
circuit board configured to communicatively connect said controller with said motor of said
20 first and second drivers, said first motion control system and said second motion control
system.