ME 5643: Mechatronics
Term Project

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Abstract

In this paper, we propose the design and the realization of a motion control system aimed at maintaining the angle of attack of the protoypical robotic swimmer in a constant flow. The device designed here utilizes direct-current motor and analog and digital sensing to implement a proportional feedback controller to maintain a user-determined yaw angle in the presence of hydrodynamic forces and perturbations in the flow field. We use the Basic Stamp 2 microcontroller as a platform.

1 Introduction

The motivation of this project stems from the study of a biomimetic swimmer designed by the Dynamical Systems Laboratory (DSL) at NYU-Poly to actively engage live fish shoals towards guiding and controlling their schooling tendency, see Fig. 1.

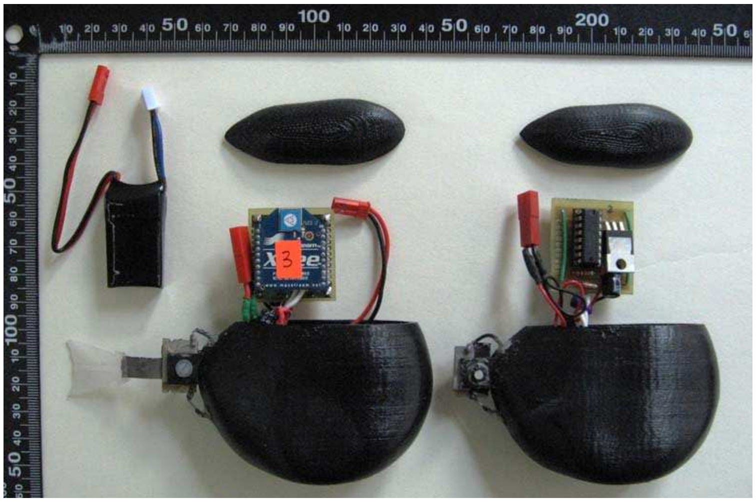

Figure 1: Prototype of the miniature fish-like robotic swimmer. The picture shows the shell of the vehicle along with bottom and top views of the onboard electronics.

In order to develop a control strategy for the vehicle, an accurate model of the system has to be devised, this including the study of the hydrodynamic actions exerted by the fluid on the body of the vehicle, see [1]. For practical purposes, we restrict the study to planar navigation. Traditionally, the planar hydrodynamic actions exerted on a body in motion through a fluid are classified as hydrodynamic drag f^D and lift f^L, respectively parallel and orthogonal to the direction of the undisturbed flow, and hydrodynamic moment m^H, see Fig. 2. Figure 2 shows the characteristic angles that describe the orientation of the vehicle body with respect to the surrounding fluid environment along with the external forces and moments acting on the body. We define the angle of attack α as the angle that the linear velocity vector $\boldsymbol{v}$ of the vehicle, whose magnitude is denoted with V, forms with the positive direction of the x axis, which is fixed with respect to the body. Further, the attitude of the vehicle with respect to the inertial frame is expressed by the yaw angle ψ between the x and the X axes. More specifically, hydrodynamic actions can be generally described using the following relations, see for example [2, 3]

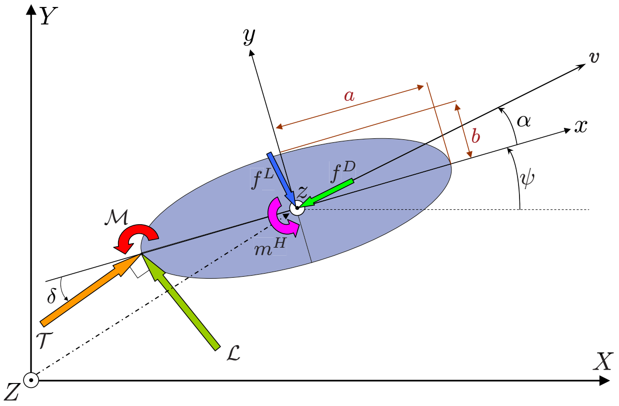

Figure 2: Schematic of the planar motion of the vehicle body. The vehicle body is approximated by an ellipse moving in the plane. Calligraphic letters refer to external actuation.

$$f^D = \frac{1}{2}\rho V^2 S C_D \tag{1a}$$

$$f^L = \frac{1}{2}\rho V^2 S C_L \alpha \tag{1b}$$

$$m^H = \frac{1}{2}\rho V^2 S(2a)\left[C_{M\alpha}\alpha + \frac{2a}{V}C_{Mr}r\right] \tag{1c}$$

where r is the yaw rate, that is, the angular velocity of the body in its yaw motion, ρ is the mass density of water, $2a$ is the characteristic length of the body, and S is a suitably defined reference surface area for the body. Several definitions are commonly used in the literature, such as wet surface area or planform area, see for example [4, 5]. In Eqs. (1), the coefficient of drag C_D, coefficient of lift C_L, coefficient of hydrodynamic restoring moment $C_{M\alpha}$, and coefficient of hydrodynamic viscous moment C_{Mr}, are dimensionless geometric properties. From a physical point of view, the hydrodynamic actions are mainly due to uneven pressure distribution effects, to viscous effects, and to skin friction. The capability to relate the entity of the hydrodynamic damping effects on the motion of a body to the navigation regime characteristics, such as velocity, direction with respect to the flow, and yaw motion and, ultimately, to determine the values for the drag, lift and moment coefficients, that is, C_D, C_L, $C_{M\alpha}$, and C_{Mr}, is of practical interest in the design of efficient exterior shapes for underwater vehicles. We note that, in general, these coefficients depend on the Reynolds number and on the angle of attack α. More specifically, a pertinent Reynolds number for the application under study is $\mathrm{Re}_a = 2aV/\nu$, where ν is the kinematic viscosity of water, that equals $10^{-6}\,\mathrm{m}^2\,\mathrm{s}^{-1}$. These hydrodynamic coefficients can be computed by direct Computational Fluid Dynamics (CFD) simulations or through experiments. We note that experimental activity performed in dynamical similitude regime, that is, in Reynolds number similitude, to determine the entity of hydrodynamic actions can be more effective than numerical simulation and less time consuming.

In light of the discussion above, the long term goal is to design a feedback controller with which to measure the hydrodynamic forces acting on the shell of the swimmer at a variety of attack angles in a flow of constant rate. The motion control system must provide the capability to explore different angles of attack α as well as different yaw rates r. In such a way the four coefficients C_D, C_L, $C_{M\alpha}$, and C_{Mr} can be experimentally identified. The apparatus described in this paper is designed specifically for use in the water tunnel housed in the DSL, see Fig. 3. The completed apparatus will allow for a variety of experimental activities, including flow visualization and force and moment measurement. In this paper we describe the design and realization of the motion control system, that allows for precise positioning of the model of the body under study with respect to the flow direction. Further work will be devoted to the development of the sensing system, needed for the actual measurement of the hydrodynamics actions exerted by the flow on the body.

Figure 3: Water tunnel housed in the Dynamical Systems Laboratory.

1.1 Design goals and specifications

Beyond the physical structure which uses the Basic Stamp 2 microcontroller, a feedback controller using a direct-current motor was designed to autonomously calibrate the swimmer's acceptable range of motion, and given an input, maintain the swimmer at the desired angle of attack. Further, the system is designed to guarantee the capability to track a step or ramp input.

The specifications of the project are as follows:

- The device is controlled by BS2.
- The device incorporates and documents hardware and software features to prevent damage to the BS2 IC and other components on the device, including guidelines for its safe operation.
- The device includes a provision for instantaneous shutdown in the case of incorrect/unsafe operation.
- The device includes a user interface so that a human user can monitor and control it.
- The device utilizes an actuator that is controlled using sensory feedback.
- The device utilizes an analog and a digital sensor.

2 System description

2.1 Mechanical design

The mechanical design addresses the problem of developing and realizing a device that is able to achieve one-axis precise positioning to study the effect of the angle of attack α of a body in an essentially planar navigation, on the forces and moments experienced. The specific geometry of the water tunnel imposes severe limitations on the dimensions of the device, that must preserve the flow pattern around the body. In addition, preliminary design considerations indicate that the model of the body should be oriented with an arbitrarily selected angle of attack with respect to the flow direction. The positioning system should be placed in a section of the water tunnel sufficiently far from the outlet and from the walls, to allow for a fully developed flow and to avoid wall effects. Hence, the degrees of freedom related to the translation in the horizontal plane are not considered in this study and we focus only on the degree of freedom pertaining to the rotation in the motion plane, that is, on the yaw motion.

The natural solution consists of a vertical rotating shaft actuated by using a DC motor. A single vertical rotating shaft can be practically used to control the angle of attack of the body with respect to the direction of the flow. The choice between DC motors and stepper motors is in this case driven by the ease of realization of the practical implementation and by cost analysis. Typically, DC motors exhibit high angular velocity at the output shaft and low actuation torques. The design specifications, on the other hand, require for the presented application high torques, in order to guarantee precise positioning under the disturbances due to the hydrodynamic actions exerted by the flow, and limited speed. Hence, a mechanical transmission needs to be employed, to cause a significant reduction in the angular velocity of the output shaft and, consequently, high torques available to overcome the fluid actions.

Several choices are available to develop a mechanical transmission suitable for meeting the design specifications, for example chains, belts or gears can be considered. A preliminary design based on the consideration of the desired high positioning precision, limited overall dimensions, and high stiffness of the assembly hints for the adoption of a gear transmission. Spur gears are selected for ease of transmission design, ease of practical assembly and ready availability, over a variety of possible choices. A rough preliminary design is sufficient for the application under analysis, mainly due to the low speeds and powers involved. A schematic of the mechanical assembly of the single stage gear transmission is provided in Fig. 4. Here, we note that the DC motor is assumed to have a built-in gear train that is designed to lower considerably the angular velocity of its output shaft. Forces are mutually exerted between the pinion and the gear along the pressure line, inclined at the angle ϕ, in the xy plane. The pinion is directly attached to the motor output shaft, and the motor is assumed to be rigidly attached to the frame on which exerts the actions X_p and Y_p. The actuated shaft, rigidly connected to the driven gear, is supported by two bearings that provide both absolute positioning and force reactions X_1, X_2, Y_1, and Y_2 from the frame. The bearings are needed to counteract the thrust on the driven gear from the pinion, embodied by the two components $F\cos\phi$ and $F\sin\phi$. The preliminary dimensioning of the elements of the transmission leads to the design of the complete assembly. A detailed view of a section of the mechanical transmission is provided in Fig. 5, whereas the full assembly is proposed in Fig. 6.

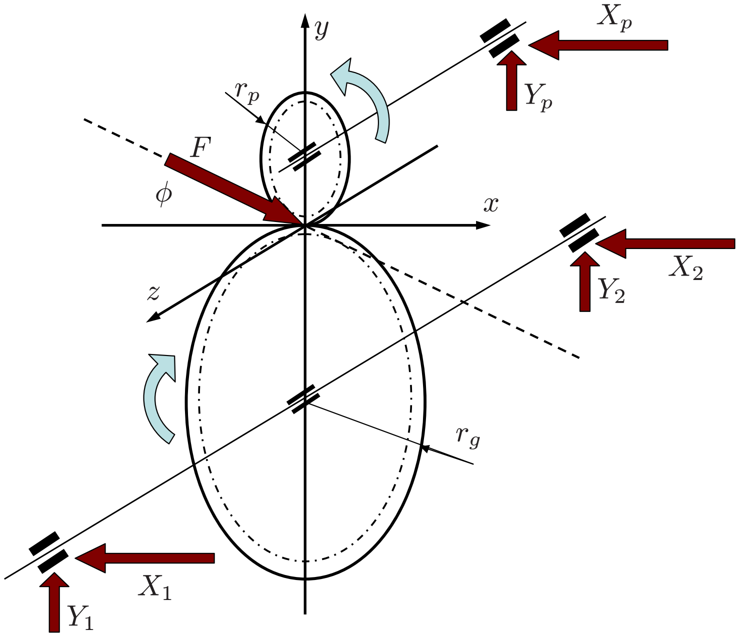

Figure 4: Schematics of the gear transmission. We indicate the direction of rotation of the two gears and the meshing forces resulting from the contact, along with the reactions exerted by the rigid support, through the bearings.

The main structure comprises a support bottom base realized from a 6.5 mm thick plexiglass where a ball bearing is countersunk. The outer ring of the ball bearing is rigidly

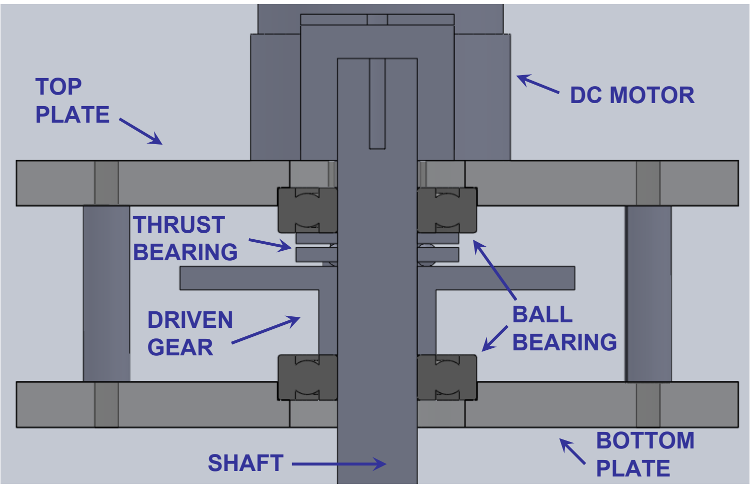

Figure 5: Detailed view of a section of the mechanical transmission. Ball bearings provide reactions to the thrust on the gear from the pinion during the motion. The thrust bearing decouples the driven gear from the outer and inner ring of the upper bearing. Structural stiffness is provided by the fastened top and bottom plate.

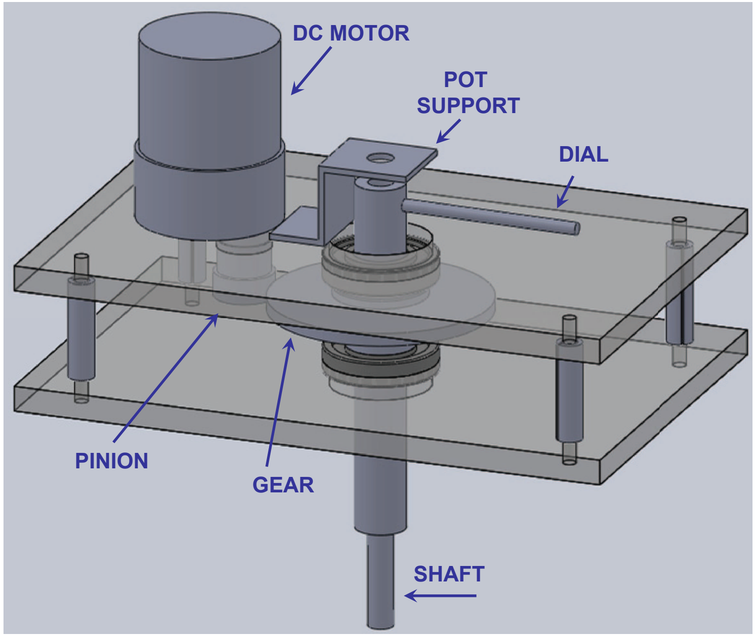

Figure 6: Axonometric view of the designed assembly. The DC motor actuates through a pinion-gear mating the shaft whose position is constantly monitored through a potentiometer fixed to the top plate.

attached to the base, whereas the inner ring is rigidly attached to a rotating shaft. The shaft is made of solid aluminum and its diameter is approximately 12.9 mm. The shaft is also connected to the driven spur gear for motion transmission, to a second ball bearing and to a thrust bearing. The bearings are held in place through a countersink in a top plate realized from a second 6.5 mm thick plexiglass. The precise distance between the top and bottom plates can be obtained through four tension screws. The rotating shaft is actuated by a DC motor that is rigidly attached to the top plate. The DC motor is rated for up to 12 V operation and has a built-in gear box whose transmission ratio is 100 : 1. Typical maximum efficiency speed for the motor is approximately equal to 35 rpm, corresponding to a maximum torque approximately equal to 0.2325 N m. Transmission is obtained through meshing of the driven spur gears with the pinion attached to the motor shaft. The transmission ratio is 11 : 3 and is selected in order to enhance the positioning precision and to further decrease the angular velocity of the actuated shaft. A hole in the top part of the shaft provides housing for a potentiometer, used as the main position sensor on the device. The potentiometer is then held in place by a specifically designed support, rigidly connected to the top plate. A dial rigidly attached to the rotating shaft controls two limiting switches, not represented in Fig. 6. The switches determine the range of safe and stable operation of the device. In addition, the dial serves as a visual feedback of the rotation and performs the initial calibration of the device, as illustrated in what follows. A view of the fully assembled device is provided in Fig. 7.

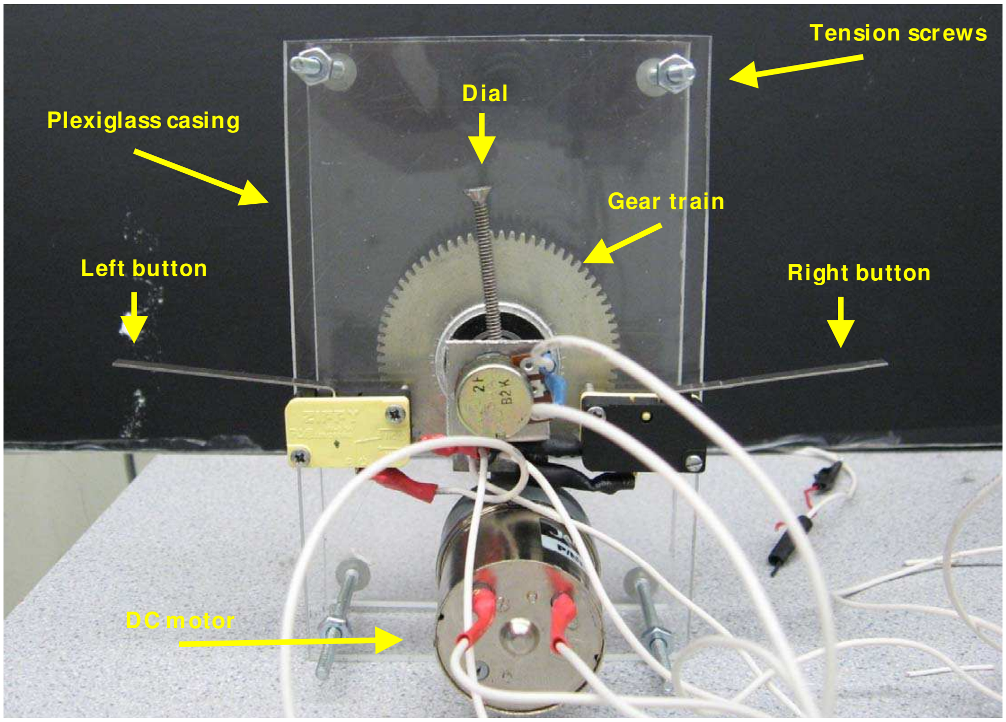

Figure 7: View of the fully assembled mechanical device.

2.2 Electrical design

The electrical design addresses two main areas, namely, the development of the power circuitry necessary for the actuation and the sensing capability of the system and the circuitry related to the implementation of the human interface through which the operator is able to control the machine and to receive feedback of correct operation. The actuation of the DC motor is obtained by controlling the supplied voltage by the means of an H-Bridge, see Fig. 8. The H-Bridge consists of four BJT power transistors, diodes to protect the circuitry from inductive kickback from the motor, and various interfacing resistors. The control inputs to the H-Bridge are directly connected to two pins of the BS2 microcontroller and suitably controlled, in order to provide the desired actuation characteristics, as explained

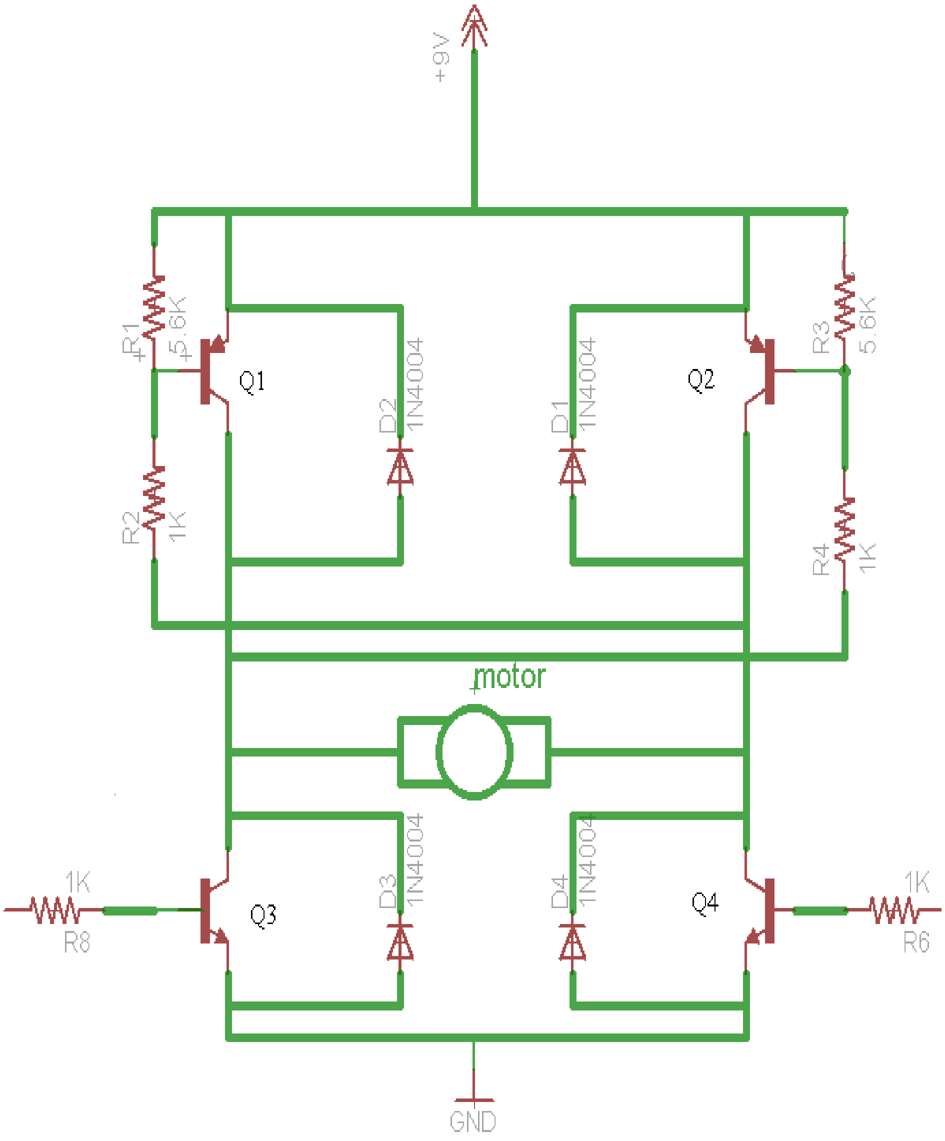

Figure 8: Schematic of the H-Bridge assembly.

below. More specifically, the control system is capable of regulating the voltage input to the motor, and to adjust its polarity, by varying it in the range from 0 V to the nominal voltage of the external power supply employed for the motor. In the application discussed herein, the selected external power supply is a 9 V battery. The sensing capability of the device relies on a potentiometer to monitor the actuated shaft angular position and in two limiting switches that ensure safe and stable range of operation. The aforementioned range spans approximately ±90° and is carefully determined through self-calibration at the beginning of each phase of operation, to ensure positioning precision. A view of the fully assembled electric circuit is provided in Fig. 9.

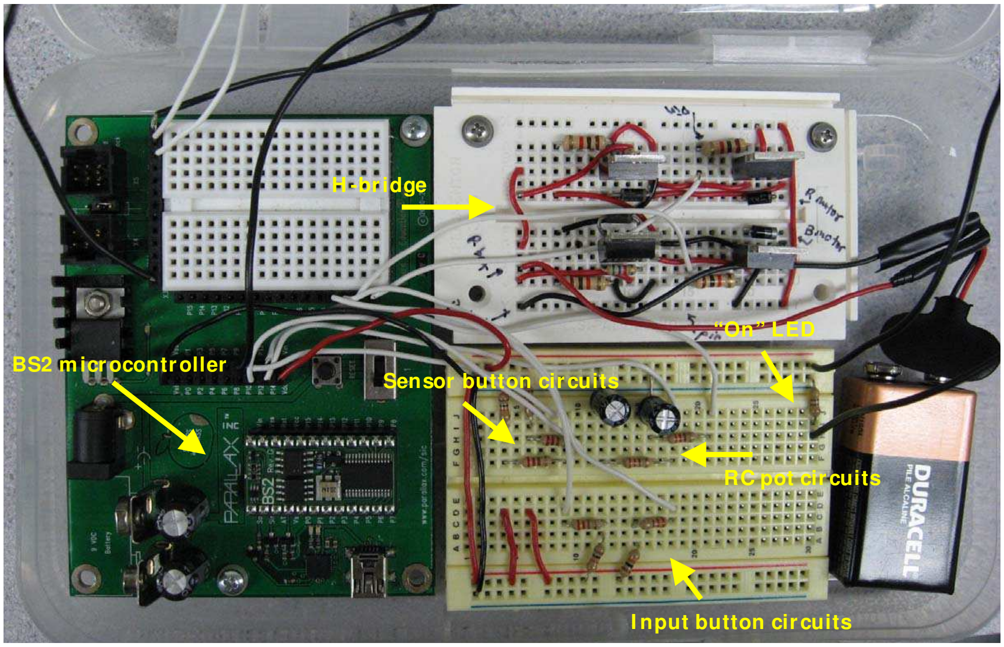

Figure 9: View of the fully assembled electric circuit.

2.3 Human interface device

The interface of this system with a human user has two components, namely, a manual activation and deactivation of the BS2 microcontroller and the DC motor, and a manual input of a desired angle of attack. The manual activation and deactivation control allows the user to control the on-state of the microcontroller and the motor independently with a double pole double throw switch, which is mainly applicable in normal and emergency shut-off situations. The user has several options in inputting a desired position for the actuated shaft, which are illustrated on the LED display available from Parallax and can be selected by using two buttons. Further, the buttons or a rotational reference potentiometer, allow the user to specify a step or ramp input with adjustable slope, or have a real-time tracking mode. In addition, the device can be reset without recalibration using a button, and recalibrated using a switch. Lastly, an LED is lit when the microcontroller is on, to provide visual feedback of the operation state of the device to the user. A view of the human interface device, or control panel, is provided in Fig. 10. A general overview of the schematics adopted

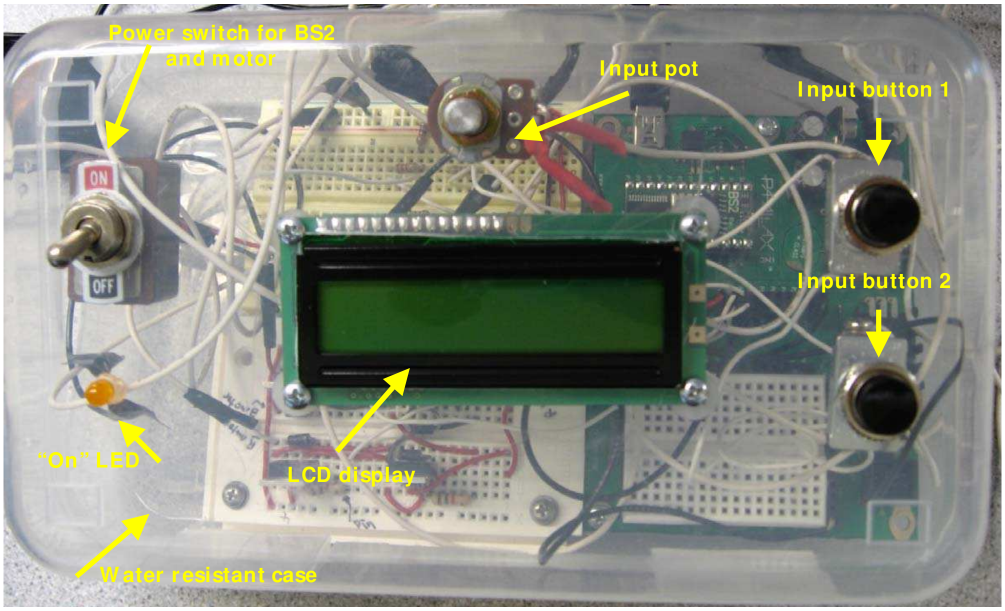

Figure 10: View of the fully assembled human interface device.

for digital and analog input devices, that is, pushbuttons and rotational potentiometers is provided in Fig. 11.

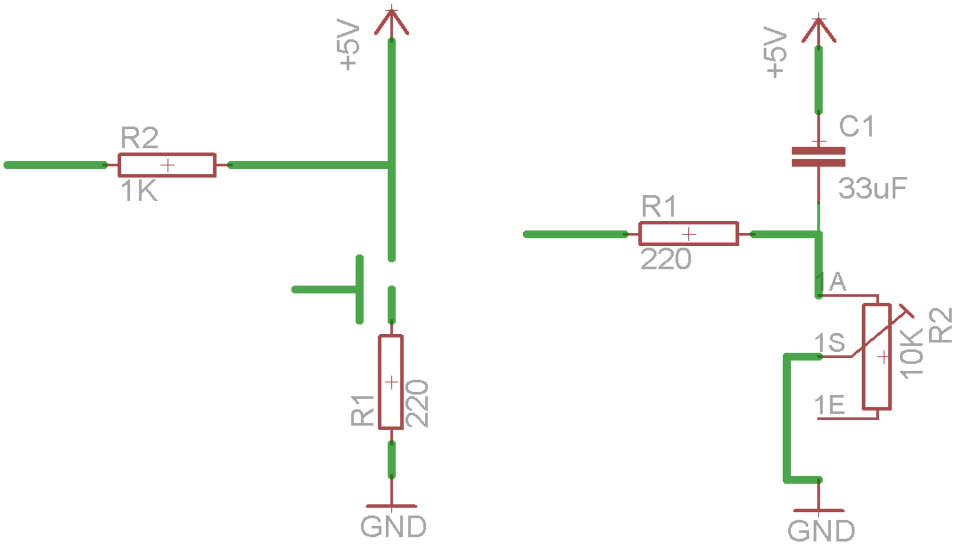

Figure 11: Example of BS2 interfacing of analog and digital input devices.

3 Control strategy

3.1 Modeling

The modeling of the system is based on the classical simplified assumptions usually adopted for armature controlled DC motors, see for example [6]. More specifically, the electrical and mechanical subsystems can be described by using the following linear ordinary differential equations

$$L\frac{\mathrm{d}i(t)}{\mathrm{d}t} + Ri(t) = V(t) - V_b(t) \tag{2a}$$

$$J\frac{\mathrm{d}\omega(t)}{\mathrm{d}t} + b\omega(t) = \tau(t) \tag{2b}$$

where L denotes the inductance of the DC motor, R the electrical resistance, $i(t)$ the current, $V(t)$ the voltage applied at the poles of the DC motor, $V_b(t)$ the back electromotive force, J the moment of inertia reduced to the motor shaft, b a viscous-type dissipative action, $\omega(t)$ the angular velocity of the motor shaft, and $\tau(t)$ the torque reduced to the motor shaft. Here, we consider the voltage $V(t)$ as an input to the system. In addition, the following relations are assumed to hold among the introduced physical quantities

$$\tau(t) = k_m i(t) \tag{3a}$$

$$V_b(t) = k_e \omega(t) \tag{3b}$$

that is, the torque is proportional to the current and the back electromotive force is proportional to the shaft angular velocity. Further, the angular position of the motor shaft θ_s can be related to the angular velocity ω through integration, and the presence of transmission gears can be accounted for by considering a proportionality constant, or transmission gain k_t, between θ_s and the position θ of the actuator shaft. The block diagram implementation of the proposed model is shown enclosed in a dashed line in Fig. 12, where Laplace transform has been used. The electrical and mechanical subsystems are clearly identified, along with the defined relations (2) and (3). Further, we note that the transmission gears implement a gain k_t on the forward branch. Figure 12 also shows the schematics of the chosen control

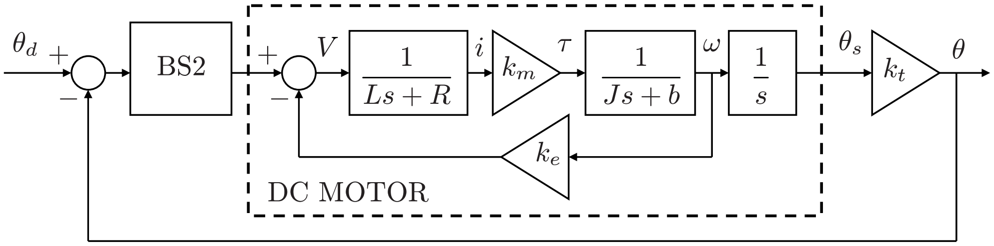

Figure 12: Block diagram implementation of the model of the system. The dashed line encloses the model of the DC motor. The actuation signal $V(t)$ is provided to the motor by the microcontroller BS2 through evaluation of the mismatch between the desired and the actual position of the actuated shaft $\theta_d - \theta$.

strategy. In particular, we implement a feedback control based on the direct measurement of the angular position of the actuator shaft θ. The sensed value is then compared to a reference input value θ_d, thus resulting in a control action on the amplitude of the driving voltage V supplied to the DC motor. The comparison and the control actions are performed by the Basic Stamp 2 microcontroller.

3.2 Algorithm description

The design specifications require the system to be able to track a given step input or a given ramp input. The rise time is not a fundamental issue given that the measurements will be executed in quasi steady state conditions. The system should also be able to exert sufficient torques in order to reject disturbances to the positioning of the body, due to the actions of the flow. The algorithm implemented in the device by the BS2 initializes with calibrating the shaft position by sensing the extreme right and left positions, and placing the shaft in the mean position. The user is then instructed to choose an input mode, meaning input a step or ramp input using the buttons, or enable real-time tracking using the reference potentiometer.

The step input tracking, whether the input is specified through button or potentiometer selection, relies on a proportional control of the voltage level supplied to the DC motor. More specifically, the voltage signal supplied to the DC motor follows the guidelines depicted in Fig. 13.

The difference between the desired and the sensed angular position is multiplied by a gain K, and the obtained value is used as the high time t_h in the voltage wave, that is

$$t_h = K(\theta_d - \theta)$$

The low time t_l is kept approximately constant, and is related to the time required by the code to execute all the measurements and display operations. The voltage wave is then a square wave whose frequency $f = 1/(t_h + t_l)$ and duty cycle $DC = t_h/(t_h + t_l)$ are varied, depending on the mismatch between the reference and the actual position. In other words, the difference $\theta_d - \theta$ controls the mean value of the voltage input to the DC motor. As the position error $\theta_d - \theta$ approaches zero, the control effort approaches zero as well, and so does the voltage wave mean value. The gain K is carefully calibrated as a compromise of swiftness of response and onset of undesired oscillatory behavior, taking also into account the presence of possible overshoot. After parameter calibration, the duty cycle of the square wave can be estimated to vary in the range 0%–±90%, corresponding to a position error of approximately 0° to 180°. During the tracking operation, the reference position can be reset at any time by pressing a button as instructed.

In a similar fashion, the ramp tracking relies on same practical technique to control the rotational speed of the motor. The speed is regulated through the sensed value of the resistance of a potentiometer, whose value can be continuously adjusted. The actuated shaft position is constantly monitored to ensure that θ is inside the allowed range. When the left or right boundaries are encountered, the direction of rotation is reversed.

We note that the proposed control system is capable of addressing the two main problems underlined in the Introduction, that is, to guarantee the positioning with a given angle of

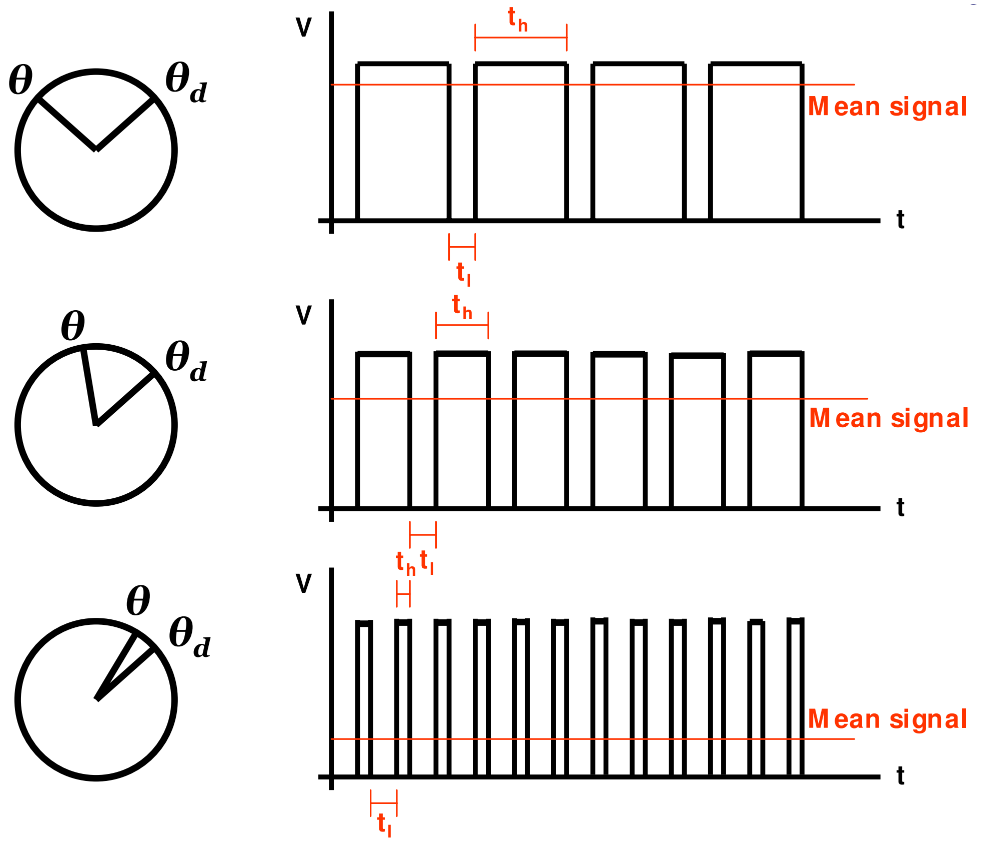

Figure 13: Schematic representation of the control strategy. The voltage square wave is represented in correspondence of an arbitrary position error, and the resulting mean voltage value supplied to the DC motor is illustrated.

attack α and the simulation of yaw motion with a given yaw rate r. These simulation conditions are essential for the study of the coefficients of hydrodynamic drag, lift, and moment.

In addition, we note that a proportional-integral control has been studied for the proposed application but it did not show superior performance with respect to the simpler proportional control. Further application of the PI control has hence been discarded.

3.3 Calibration

The automatic calibration of the device facilitates ease of use, as well as defines the normal parameters of operation to the microcontroller. The DC motor is programmed to turn the shaft to the left boundary, at which point an arm on the shaft depresses a button. The Basic Stamp 2 then measures and saves the measured value of the resistance of the sensor potentiometer using the `RCTime` command. This process is repeated at the right boundary, and the mean of the RCTime values is calculated to provide the zero angle of attack reference. We note that the limiting switches are fixed to allow a range of approximately 180°. The motor then moves the shaft to the mean position using the feedback control algorithm outlined above, with the $\alpha = 0$ employed as the reference position. This position, due to the orientation of the device on the water tunnel, points the body exactly upstream of the flow. The `RCTime` values of the boundaries are saved by the BS2, and used as the upper and lower limits for the sensor potentiometer, ensuring positioning of the body with heading into the flow.

4 Conclusions

In this work we presented the design, development, and realization of a motion control system to be utilized in a force measurement device in a water tunnel. The mechanical and electrical designs have been thoroughly discussed and documented. The selected control strategy has been described and the practical implementation in the framework of the BS2 microcontroller has been outlined. As a result, the proposed device is able to track the desired inputs to faithfully simulate navigation conditions for underwater vehicles. Further work will be devoted to the development of the force measurement system.

A Implemented code

Attached is the code uploaded to the EEPROM of the Basic Stamp 2 microcontroller. This allows for autonomous operation, without the need of a computer interface

```
' {$STAMP BS2}
' {$PBASIC 2.5}

'Variables declaration
sens_time VAR Word
ref_time VAR Word
toler VAR Byte
```

```
diff VAR Word
leftbound VAR Word
rightbound VAR Word
middle VAR Word
ceff VAR Word
butin VAR Bit
desireddeg VAR Byte
sign VAR Bit

'Define required tolerance on the error
toler = 100


'Turn on led display and clear screen
LOW 0
LOW 1
SEROUT 11,84,[22,12]
PAUSE 5
SEROUT 11,84,["Calibrating..."]

'Start Auto-calibration
Calibrate:
DO                      'turn left
  LOW 0
  HIGH 1
  PAUSE 5
  LOW 1
  PAUSE 1
LOOP UNTIL (IN13=1)           'hit left button
LOW 1
HIGH 14
PAUSE 50
'record sensor rctime for leftbound
RCTIME 14, 1, sens_time
leftbound =  sens_time-4600
DEBUG HOME, "Left bound is at ", DEC5 leftbound

DO                      'turn right
  LOW 1
  HIGH 0
  PAUSE 5
  LOW 0
  PAUSE 1
LOOP UNTIL (IN12=1)                  'hit right button
LOW 0
HIGH 14
PAUSE 50
 'record sensor rctime for rightbound
RCTIME 14, 1, sens_time
rightbound =  sens_time+300
DEBUG HOME, CR, "Right bound is at ", DEC5 rightbound

'Define mid-point between leftbound and rightbound (0 degrees)
Initialization:
```

```
middle=(leftbound-rightbound)/2+rightbound-500
DEBUG HOME, CR,CR, "middle ",  DEC5 middle

'Put the shaft in the 0 degrees position
DO
  HIGH 14
  PAUSE 20
  'monitor sensor angular position
  RCTIME 14, 1, sens_time

  'Define error between actual and mid position
  diff=middle-sens_time



  DEBUG HOME, CR,CR, CR,"sens_time ",DEC5 sens_time

'Move the shaft until error is below tolerance
  GOSUB actuate
LOOP UNTIL (diff<toler)



'Enter input mode
inputMode:
'turn on lcd display and clear screen
SEROUT 11,84,[22,12]
PAUSE 5


SEROUT 11,84,["B1:button input",13,"B2:pot input"]



'Wait until B1 or B2 are pressed
DO
LOOP UNTIL ((IN3=1) OR (IN2=1))

SEROUT 11,84,[12]
PAUSE 5

 'select input with pushbuttons
IF (IN3=1) THEN
  DO
  LOOP UNTIL (IN3=0)
  GOTO refButton
 SEROUT 11, 84,["You want buttons!"]
ELSE  'select input with potentiometer
  DO
  LOOP UNTIL (IN2=0)
  GOTO refPot
  SEROUT 11,84,["You want pot!"]
ENDIF
PAUSE 1000
```

```
'Enter potentiometer mode
refPot:
SEROUT 11,84,[22,12]   'turn on lcd display and clear screen
PAUSE 5
SEROUT 11,84,["B1:step input",13,"B2:ramp input"]

'Wait until B1 or B2 are pressed
DO
LOOP UNTIL ((IN3=1) OR (IN2=1))
SEROUT 11,84,[12]
PAUSE 5

IF (IN3=1) THEN
DO          'select step input
LOOP UNTIL (IN3=0)
 GOTO mainPot
 SEROUT 11, 84,["You want step!"]
ELSE
DO                     'select ramp input
LOOP UNTIL (IN2=0)
  GOTO rampPot
  SEROUT 11,84,["You want ramp!"]
ENDIF
PAUSE 1000

'Enter pushbuttons mode
refButton:
SEROUT 11,84,["Input position"]
PAUSE  500
SEROUT 11,84,[12]
PAUSE 5
SEROUT 11,84,["B1 to go left",13, "B2 to go right"]

'Wait until B1 or B2 are pressed
DO
LOOP UNTIL ((IN3=1) OR (IN2=1))
SEROUT 11,84,[12]
PAUSE 5

IF (IN3=1) THEN             'Select to turn left
DO
LOOP UNTIL (IN13=0)
 butin = 0
 SEROUT 11, 84,["You want left"]
ELSE                        'Select to turn right
DO
LOOP UNTIL (IN12=0)
 butin = 1
  SEROUT 11,84,["You want right"]
ENDIF
PAUSE 1000
```

```
SEROUT 11,84,[12]
PAUSE 5

SEROUT 11,84,["B1 for yaw degs",13,"B2 when done"]
PAUSE 1500

desireddeg = 0      ’set initial value to 0 deg

SEROUT 11,84,[12]
PAUSE 5

’Count button 1 presses (desired degrees)
countDegrees:
DO
LOOP UNTIL ((IN2=1) OR (IN3=1))
  IF (IN3=1) THEN
    DO
    LOOP UNTIL (IN3=0)
    desireddeg = desireddeg + 1
    SEROUT 11,84,[128,DEC2 desireddeg, " degrees"]
    GOTO countDegrees
  ELSEIF (IN2=1) THEN
  DO
  LOOP UNTIL (IN2=0)
    GOTO displaydeg
  ENDIF

’Display desired angle of attack
displaydeg:
SEROUT 11,84,[12]
PAUSE 5

’Convert desired value in degrees in rctime units
IF butin=0  THEN

  ref_time = middle+(desireddeg*((leftbound-middle)**728) )
  SEROUT 11, 84, [128,"Ref:",DEC2 desireddeg," deg left",148,"B1 for reset"]
ELSE

  ref_time = middle-(desireddeg*((middle-rightbound)**728) )
 SEROUT 11, 84, [128,"Ref:", DEC2 desireddeg," deg right",148,"B1 for reset"]
 ENDIF

’errint=0
mainButton:
DEBUG HOME, CR, "main button"

’Record actual position of the shaft
  HIGH 14
  PAUSE 20
  RCTIME 14, 1, sens_time

’Correct if required position lies outside boundaries
  IF (ref_time>leftbound) THEN
```

```
    ref_time=leftbound-100
  ENDIF
  IF (ref_time<rightbound) THEN
    ref_time=rightbound+100
  ENDIF

  'Define error between desired and actual angular position
  diff = ref_time-sens_time

  DEBUG HOME, CR, CR,  CR,CR, CR, "Sensor: ", DEC5 sens_time
  DEBUG CR, "Reference: ", DEC5 ref_time

  DEBUG CR, "Difference: ", SDEC4 diff, CR

  'Monitor state of reset button
  IF (IN3=1) THEN
    DO
    LOOP UNTIL (IN3=0)
    GOTO inputMode
  ENDIF

  'Move the shaft until required angle is reached
  GOSUB actuate

GOTO mainButton

mainPot:
'Monitor actual and reqired angular position for the shaft
  HIGH 14
  HIGH 15
  PAUSE 20
  RCTIME 14, 1, sens_time    'actual position
  RCTIME 15, 1, ref_time     'required position

 SEROUT 11,84,[22,12]     'turn on lcd display and clear screen
  PAUSE 5

  'Convert required angle in degrees and display it on LCD display
   IF (ref_time>middle)  THEN

        desireddeg=(ref_time-middle)/((leftbound-middle)/90 )

        DEBUG HOME, CR, CR, CR, DEC5 desireddeg
        SEROUT 11,84,[128,"Ref:",DEC2 desireddeg," deg left",148,"B1 for reset"]
   ENDIF
   IF  (ref_time<middle) THEN

        desireddeg=(middle-ref_time)/( (middle-rightbound)/90)

        DEBUG HOME, CR, CR, CR, DEC5 desireddeg
        SEROUT 11,84,[128,"Ref:",DEC2 desireddeg ," deg right",148,"B1 for reset"]

   ENDIF
```

```
   'Correct if required position lies outside boundaries
  IF (ref_time>leftbound) THEN
    ref_time=leftbound-100
  ENDIF
  IF (ref_time<rightbound) THEN
    ref_time=rightbound+100
  ENDIF


  'Define error between desired and actual angular position
  diff = ref_time-sens_time
  DEBUG HOME, CR, CR,  CR,CR, CR, "Sensor: ", DEC5 sens_time
  DEBUG CR, "Reference p: ", DEC5 ref_time
  DEBUG CR, "Difference: ", SDEC4 diff

  'Monitor state of reset button
  IF ( IN3=1) THEN
  DO
    LOOP UNTIL (IN3=0)
    GOTO inputMode
  ENDIF

  'Rotate shaft until required position is reached
  GOSUB actuate


GOTO mainPot

sign=0

rampPot:

DEBUG CR,CR,CR,CR,CR,CR,CR,"ramp ref time is",DEC5 ref_time

'Monitor actual angular position of the shaft and required velocity
  HIGH 14
  HIGH 15
  PAUSE 20
  RCTIME 14, 1, sens_time         'angular position
  RCTIME 15, 1, ref_time          'required velocity

  'Define direction of rotation
  IF ( ((sens_time>leftbound-500) AND (sign=0)) OR ((sens_time<rightbound+500) AND (sign=1)) ) THEN
    sign=sign+1
  ENDIF
  DEBUG HOME, CR, CR,  CR,CR, CR, "Sensor: ", DEC5 sens_time

  'Rotate the shaft back and forth with required velocity
  GOSUB actuateRamp


GOTO rampPot

'Rotate the shaft back and forth at constant velocity
```

```
actuateRamp:


 'Monitor state of reset button
  IF (IN3=1) THEN
    DO
    LOOP UNTIL (IN3=0)
    GOTO inputMode
  ENDIF

    ceff = ref_time**1500   'define high time for the pulses (proportional to required velocity)

    IF (sign=1) THEN   ' turn right (ccw)
      LOW 1
      HIGH 0
      PAUSE ceff
      LOW 0

    ELSE          ' turn left  (cw)
      LOW 0
      HIGH 1
      PAUSE ceff
      LOW 1
    ENDIF


RETURN

'Rotate shaft until desired position is reached
actuate:

'Define the sign the error between desired and actual angular position
  sign=diff.BIT15
  diff=ABS(diff)

  IF (diff>toler) THEN
  'check if required position is reached within a certain tolerance

    'Define gain proportional to the error
    ceff = diff**700

    IF (sign=1) THEN
    ' turn right (ccw)
      LOW 1
      HIGH 0
      PAUSE 1+ceff
      'define duration of high pulses (proportional to gain ceff)
      LOW 0

    ELSE
    ' turn left  (cw)
      LOW 0
      HIGH 1
      PAUSE 1+ceff
```

```
      LOW 1
    ENDIF

  ELSE
  'keep desired position
    LOW 1
    LOW 0
    PAUSE 2

  ENDIF
RETURN
```

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