Date:	09 Dec 1996
Student Name:	Kevin McFarlin
TA:	Scott Jantz
Instructor:	Keith L. Doty

University of Florida
Department of Electrical Engineering

EEL 5934
Intelligent Machines Laboratory

Big Mac:
The Migrating Robot

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Abstract

Big Mac is an autonomous migrating robot. It has four types of sensors -- tactile sensor, IR emitter/detectors, tilt sensor, and digital compass. The robot uses these sensors to integrate four different behaviors -- bump reaction, collision avoidance, tilt reaction, and migration.

Executive Summary

The purpose of this project was to design a migrating robot which could negotiate obstacles during the migration. The robots name is Big Mac. Big Mac's microprocessor is a Motorola 68HC11 with a Novasoft ME11 expansion board. The program code was written and compiled in ICC11 format.

Big Mac's mobile platform is octangular, and the robot rides on a pair of toy tank treads which are actuated by two servos. Big Mac uses four different types of sensors to interact with the environment. These sensors are tactil bump sensors, IR emitter/detectors, tilt sensor, and a digital compass. These sensors allow Big Mac to implement four different behaviors. These behaviors are bump reaction, collision avoidance, tilt reaction, and migration. The first three behaviors mentioned serve to allow Big Mac to *survive* in an environment. The migration behavior is the algorithm that gives Big Mac its purpose.

All four of Big Mac's behaviors operate properly. However, it is the integration of these four behaviors that allow Big Mac to perform adequately in a complex environment.

Introduction

The purpose of this project was to produce a robot which is intelligent enough to roam an area avoiding any obstacles which it may encounter. Furthermore, the robot must be capable of maintaining its orientation in any environment. The robot could then reference its orientation in order to migrate to one end of the room. This paper discusses how this was achieved.

The first topic of discussion is the integrated system. Next, the method of robot actuation will be discussed and the topic of the robot's necessary sensors will follow. The paper will close with the behavior algorithms implemented in Big Mac and its performance in a complex environment.

Integrated System

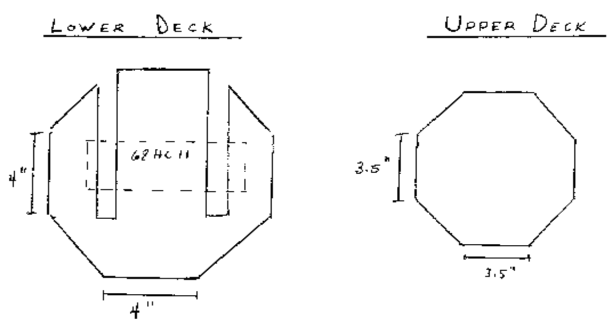
Big Mac's microprocessor is a Motorola 68HC11 with evaluation board. The microprocessor is used in expanded mode in conjunction with the Novasoft ME11 expansion board. The program code was written and compiled in ICC11 format. Big Mac's power supply consists of eight AA rechargeable batteries.

Big Mac possesses four behaviors -- bump reaction, collision avoidance, tilt reaction, and migration. Big Mac must integrate all four of its behaviors in order to achieve its goal of reaching the north end of an enclosed area. The bump reaction and collision avoidance are the fundamental necessities of an intelligent robot. Big Mac must be capable of negotiating any obstacles that it encounters in order to perform the migration behavior properly.

Mobile Platform

The robot sits on a pair of treads salvaged from a toy tank. On top of the tread system is an octangular platform. This lower deck platform serves as the basis for mounting the 68HC11 EVBU board and other essential circuitry. The platform has two 1 inch slots cut for tread clearance and several holes drilled for routing wires around the platform. Above the lower deck is another octangular platform called the upper deck. This deck serves as a cover for the circuitry and provides a mounting area for an elevated bump sensor. The upper deck is also a level platform for mounting the digital compass. The deck isolates the compass from any metal or circuitry which may influence its accuracy. A detailed diagram of the mobile platform is given in Figure 1 below.

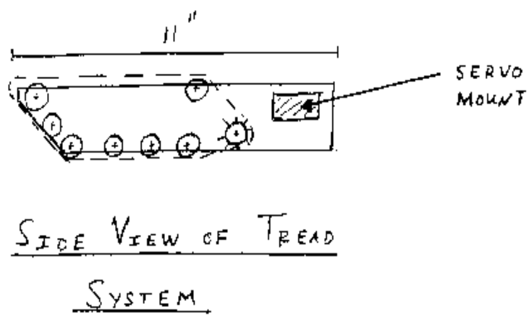
Figure 1



Actuation

The robot rests on a pair of treads with a wheel base of 4.5 inches. The treads have a row of fingers which fit into grooves in the tread guides. These fingers serve to keep the treads aligned and on the tread guides. The treads are driven by servos. A Large gear -- 50 teeth -- is epoxied to each servo. Then a smaller gear -- 20 teeth -- is epoxied to each sprocket that rotates the tank treads. These gears are meshed together to actuate the treads. This gearing system is necessary to speed up the movement of the treads because the sprocket that rotates the treads is only 0.75 inches in diameter. Figure 2 is a detailed diagram of the tread system.

Figure 2



Sensors

Tactile Sensor

Big Mac has a two level bump sensor. One level is on the lower deck of the mobile platform, and the second level is on the upper deck of the mobile platform. The sensors are made from single-pole single-throw momentary contact keyboard switches and a large, stiff nylon zip-tie. The switches are glued around the front periphery of the platforms, and the zip-tie is glued to the tip of the switches. The Figure 3 contains a diagram of the bump sensor design. Figure 4 is the circuit used to interface the bump sensor with the 68HC11.

Figure 3

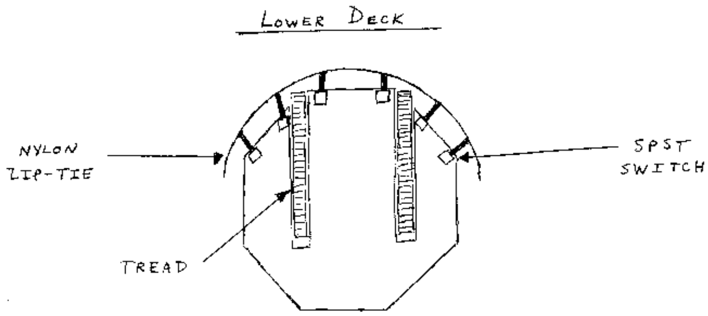
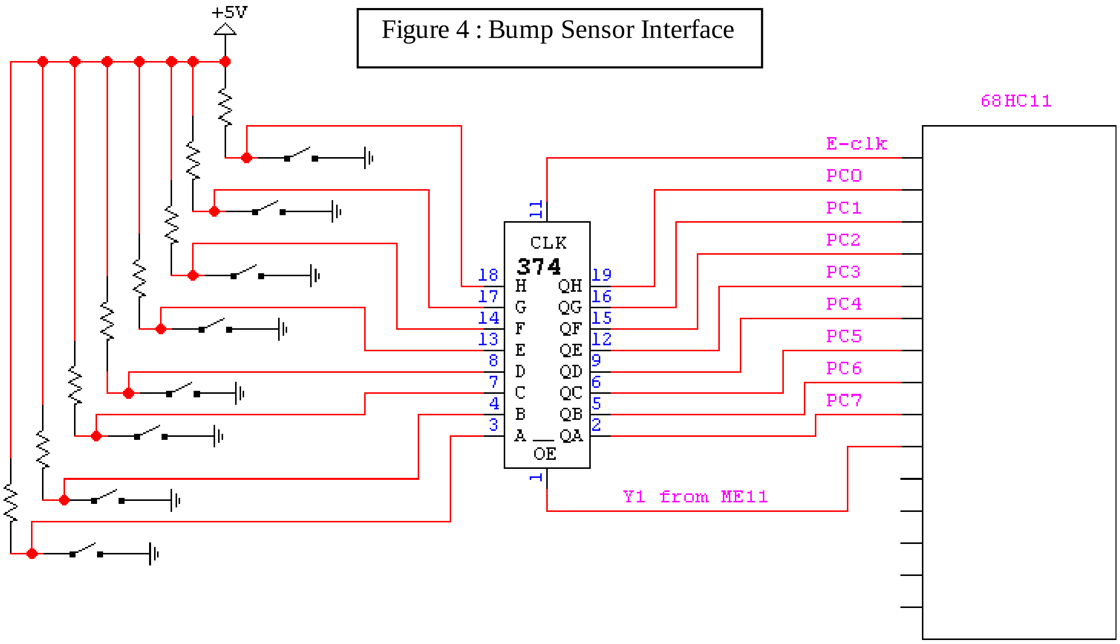


Figure 4 : Bump Sensor Interface



Big Mac has the capability to sense which side the bump occurs on. Both the upper level and the lower level bump sensors prove to be sensitive. They are an effective secondary collision avoidance sensor.

Infrared Emitter/Detector Pair

The infrared sensors consist of two components -- the IR emitter and the IR detector. The IR emitters are IR LED's which are glued to the underside of the mobile platform. The underside of the platform is painted black to cut down on the reflection of IR light from Big Mac's body. This reduces the amount of false triggering in the IR detector. The IR light is modulated at 40 kHz, and the Sharp IR detectors only detect 40 kHz modulated light. This serves to filter out any light from sources other than Big Mac's IR emitters. These sensors perform as effective primary collision avoidance sensors.

Tilt Sensor

The tilt sensor is a mercury switch from an old pin ball machine. The tilt sensor is implemented exactly like the bump sensors. Only six bump sensors are used in the diagram given in Figure 1. Therefore, the tilt switch was added on to the same circuitry. The tilt sensor bit is bit seven of address (4000)hex of the microprocessor. Bit zero through bit five of address (4000)hex is reserved for the bump sensor.

Digital Compass

The digital compass is a design by Kevin McFarlin and Jeff Webb. It was made from a PC mouse, rare earth magnets, and a 1 inch fishing bobber floating in a 35 mm film canister. A detailed description of the design is included in the appendix. The compass is the sensor that provides the robot with its relative orientation in an area. The information given to the robot by the compass allows Big Mac to implement its migration behavior.

Behaviors

Bump Reaction

When Big Mac senses a bump with its tactile sensor, the robot can sense which direction the bump came from and then decide how to react. If the bump is on the far left side, Big Mac will back up and turn slightly to the right to negotiate the obstacle. If the bump is sensed on the near left, Big Mac will back up and turn hard to the right. The robot will react similarly to bumps on the right side as well.

Big Mac also has a short term memory when it bumps into an object. If the robot experiences a bump several times at approximately the same compass coordinate, it will react in a different way from the previous times the same bump was experienced. For example, if Big Mac enters a corner in which the IR collision avoidance fails, it will generally bump on the left and then bump on the right and then bump on the left again. This sort of oscillation would continue if Big Mac did not have a short term memory. However, the robot can remember the compass coordinates of its previous two bumps and take this into consideration when reacting to the current bump.

Collision Avoidance

The IR emitter / detector pairs are the sensors used to implement this behavior. First, the speed of Big Mac is a function of the maximum IR reading. The relationship is as follows:

$$\text{base speed} = \frac{[(100 - IRmax) * 4]}{100} + 30$$

where IR max is the maximum IR reading normalized from 0 to 100. When the robot does not *see* anything -- IR max is zero -- then the speed is 70. 70 is the duty cycle of the motors. When Big Mac is within approximately 6 inches of an object IR max approaches 100. This yields a speed of 30. The relationship between IR readings and speed allow Big Mac to slow down when approaching an object. This also prevents the robot from bumping into an object at full speed.

Big Mac has four IR detectors that it utilizes for collision avoidance. There are two outer detectors -- the outer left detector and the outer right detector. There are also two inner detectors -- the inner left detector and the inner right detector. Big Mac's turn rate is dependent on the difference between these emitters. Big Mac uses two differences -- the difference between the two inner detectors and the difference between the two outer detectors. The relationship is as follows:

$$\text{turn rate} = \frac{Kouter * (outerRightIR - outerLeftIR)}{100} + \frac{Kinner * (innerRightIR - innerLeftIR)}{100}$$

where Kouter is the outer IR turn rate gain and Kinner is the inner IR turn rate gain. The turn rate represents the difference in the right and left motor speed from the robots base speed. For example, a turn rate of 35 results in the left motor being at a duty cycle of 35 above the base speed and the right motor being at a duty cycle of 35 below the base speed. This yields a right turn. Furthermore, a turn rate of -35 results in the left motor being at a duty cycle of 35 below the base speed and the right motor being at a duty cycle of 35 above the base speed. This yields a left turn. Therefore, one can understand that there are many varying turn rates and because of the feedback from the IR differences, Big Mac can have a smooth turning reaction when encountering obstacles.

Tilt Reaction

Because Big Mac has a tread system with relatively high clearance, the robot has a tendency to drive up on low lying objects without detecting them with either the bump sensors or the IR detectors. This can prove to be a problem because Big Mac could either stall its motors or flip over and turtle itself. Another problem is that the digital compass does not give an accurate reading unless the robot is level. Therefore, the tilt sensor can be used to avoid these undesired situations. When Big Mac experiences a tilt greater than 30 degrees, it will disable the other behaviors, back up, and then continue in a random direction.

Migration

The digital compass allows Big Mac to migrate to the relative north end of a room or area. Relative north is defined as the direction that Big Mac is pointing when powered up or reset. Big Mac attempts to migrate in this direction whenever an obstacle is not within the immediate path of the robot. If an object is encountered, the robot will negotiate the obstacle and then -- after the obstacle is avoided -- the robot will begin to migrate again. This behavior causes the robot to drift in a general direction. Inevitably, Big Mac will reach the furthest point north in a room. The turn rate of the robot is dependent on the compass reading only when an obstacle is not eminent. The relationship is as follows:

$$\text{migrate rate} = \text{turn rate} = \frac{\text{Kcompass} * (\text{Heading Difference})}{100}$$

where the heading difference is the difference between the relative north heading and Big Mac's current compass heading and Kcompass is the compass feedback gain. Refer to the section on collision avoidance for a detailed description on the turn rate significance.

Performance

Bump Reaction

The performance of the bump reaction algorithm is functional. The short term bump memory improves the performance by preventing the robot from becoming trapped in narrow corridors. Without the short term memory or some method of randomness, the robot would oscillate right and left because it would continue to bump the left wall and then the right wall. However, the implementation of the digital compass provides Big Mac with a reference point for which to remember where previous bumps occurred.

A drawback to the bump sensor is that it protrudes from the sides of the robot. This proves to be a problem when the robot is in a cluttered environment where items can snag the bump sensor. In the future, a more streamlined sensor needs to be designed.

Collision Avoidance

The infrared collision avoidance algorithm operates proficiently. It has the capability of making gradual corrections in the robots course and speed to maneuver around objects. However, the algorithm also works efficiently when Big Mac is approaching objects head on. The algorithm first slows down the robot and then makes the corrections necessary to negotiate the obstruction quickly.

The behavior does have problems with black objects. Yet, the algorithm is successful with most dark items other than black. There is also problems with transparent or shiny, metallic items. However, these items are nearly always detected by the bump sensors.

Tilt Reaction

The tilt algorithm serves its purpose to protect the robot from motor stall and turtling. The algorithm is simple, yet useful for a tertiary obstacle avoidance method.

Migration

The migration algorithm is the most unique behavior implemented in Big Mac. The robot clearly tries to reach the north side of the room. There are times when the migration behavior conflicts with the collision avoidance behavior. Yet, Big Mac is persistent and inevitably finds a way to migrate. This behavior can be a useful technique in getting a robot to a certain destination. The robot does not actually have a clear destination, however, if there is a north wall with a recessed area in the wall Big Mac will eventually find its way to the recess. This is mainly due to the migration behavior and randomness generated by the orientation of objects in the room. In the future, a recessed wall such as the one mentioned above can be the location of a charging station or item drop off point. So, this migration behavior can be implemented in many useful ways.

Conclusion

Big Mac overall was a success. The hardware proved to be a rather sturdy design. At first, there were doubts about the gear and tread system. However, the treads have been operating since the beginning of the project and there has been no instance of failure. The software of Big Mac proved to be adequate, yet there are still some algorithms and behaviors which need to be tested and implemented.

Some lessons learned from this project are that careful planning is required to realize a significant goal, and that goal needs to be specified from the start. This will give the designer a more structured purpose to pursue. Furthermore, a designer needs to pay close attention to detail. This sort of design approach will save time in the long run. In closing, Big Mac has been an educational project and has laid a firm foundation for more in-depth machine intelligence work in the future.

References

Jeff Webb is the author of the following ICC11 library files used by Big Mac:

multitsk.c	-- multitasking routine
timekeep.c	-- time delay routine
motcontr.c	-- servo control routine
compass.c	-- compass data capture routine

Appendix A: Big Mac Program Code

```
/****************************************************************************/
/* Robot:                    BigMac                                   */
/* Algorithms Implemented:   Differential IR steering, bump avoidance, */
/*                           migration to relative north              */
/****************************************************************************/

/*------------------------------------------------------------------------*/
/* Include files                                                          */
/*------------------------------------------------------------------------*/
 #include <multitsk.h>
 #include <timekeep.h>
 #include <serio.h>
 #include <motcontr.h>
 #include "sensors.c"
 #include <function.h>
 #include <compass.h>

/*------------------------------------------------------------------------*/
/* Defines                                                                */
/*------------------------------------------------------------------------*/
 #define motorTimeConstant 5
 #define motorSamplingPeriod 50
 #define left 0
 #define right 1

/* Bump Flag                                                              */
int urgentBump = 0;

/* Bump Variables                                                         */
unsigned char bump;
int bumpSpeed;
int bumpRate;

/* IRVariables                                                            */
int irMax;
int irSpeed;
int irRate;
int dOir;
int dIir;
int Kinner;
int Kouter;

/* Migration Variables                                                    */
int head;
int dHead;
int dHeading;
int Kcomp = 60;
int migrateRate;


/****************************************************************************/
```

```
/*                                              */
/* Bump Maneuvering: this routine takes over when a bump occurs         */
/*                                              */
/****************************************************************************/

void moveBump(int direction, int lotime, int hitime)
{
 bumpSpeed = 0;
 bumpRate = 0;
 urgentBump = 1;
 setDesiredSpeed(bumpSpeed);
 setDesiredTurnRate(bumpRate);
 delay(150);

 if (direction == left)
 {
  bumpSpeed = -75;
  bumpRate = -35;
  setDesiredSpeed(bumpSpeed);
  setDesiredTurnRate(bumpRate);
  delay(random(lotime,hitime));
 };
 if (direction == right)
 {
  bumpSpeed = -65;
  bumpRate = 35;
  setDesiredSpeed(bumpSpeed);
  setDesiredTurnRate(bumpRate);
  delay(random(lotime,hitime));
 };

 bumpSpeed = 0;
 bumpRate = 0;
 setDesiredSpeed(bumpSpeed);
 setDesiredTurnRate(bumpRate);
 delay(150);

 bumpSpeed = 70;
 bumpRate = 0;
 setDesiredSpeed(bumpSpeed);
 setDesiredTurnRate(bumpRate);

 urgentBump = 0;
}

/****************************************************************************/
/*                                              */
/* Bump Avoidance: arbitrates how to react to the bump                  */
/*                                              */
/****************************************************************************/
void avoidBump()
{
 while(1)
 {
  bump = getBumpValue();
```

```
    if (bump == 0) urgentBump = 0;
    if (bump != 0)
    {
      urgentBump = 1;
      if (bump == 1) moveBump(right,500,750);
      else if ((bump != 1) && (bump <= 3)) moveBump(right,1000,1500);
      else if ((bump > 3) && (bump <= 7)) moveBump(right,1500,2500);
      else if ((bump > 7) && (bump <= 8)) moveBump(left,2000,2500);
      else if ((bump > 8) && (bump <= 31)) moveBump(left,1500,2000);
      else if ((bump > 31) && (bump <= 63)) moveBump(left,750,1000);
     };
  };
}

/**************************************************************************/
/*                                                                        */
/* IR Avoidance: uses the difference between the two outer ir and the    */
/*              and the difference between the two inner ir to steer the */
/*              robot.  The speed is a function of the maximum ir reading*/
/**************************************************************************/
void diffIR()
  {
   while(1)
   {
     int i;
     int ir[6];
     for(i=0; i<6;i++)
       ir[i] = getIR(i);

/*Find maximum of ir array*/
     irMax = max(ir,6);

/*Determine ir differential*/
     dOir = ir[outerLeft] - ir[outerRight];
     dIir = ir[innerLeft] - ir[innerRight];

/*Determine ir turn rate gains*/
     if ((irMax > 50) && (abs(dOir) < 10))
       Kouter = 700;
     else
       Kouter = 50;
     if ((irMax > 50) && (abs(dIir) < 10))
       Kinner = 1000;
     else
       Kinner = 75;

/*Compute ir speed*/
     irSpeed = ((100 - irMax) * 7) / 10 + 20;

/*Compute ir turn rate*/
     irRate = Kouter * dOir / 100 + Kinner * dIir / 100;
    };
}

/**************************************************************************/
```

```
/* Compass migration routine: the robot uses the compass to migrate to    */
/*                         relative north.  Relative north is defined  */
/*                         by the direction the robot is pointed when  */
/*                         reset is pressed.                          */
/***************************************************************************/

void migrate()
{
 while(1)
 {
  head = getHeading();
  dHead = 360 - head;
  if (dHead > 180)
   dHeading = dHead - 360;
  else
   dHeading = dHead;

/*Compute migration turn rate*/
   migrateRate = Kcomp*dHeading/100;
 };
}

/***************************************************************************/
/*   Debugging: prints to screen the crucial parameters                   */
/***************************************************************************/

void debug()
{
 while(1)
 {
   printf("Ready...\n");
   printf("IR Speed:       %d \n",irSpeed);
   printf("IR Rate:        %d \n",irRate);
   printf("Migration Rate: %d \n",migrateRate);
   printf("Heading:        %d \n",head);
   printf("dHeading:       %d \n",dHeading);
   printf("Bump:           %d \n",bump);
   printf("Urgent Bump:    %d \n",urgentBump);
   home();
 };
}

/***************************************************************************/
/* Main Program                                               */
/***************************************************************************/

main()
 {

/*  Initializations                                         */
    initTimeKeeper();
    initMultiTasking();

/*  Initialize I/O devices                                   */
    initSensors();
```

```
      initCompass();

/*  Initialize Control Processes                              */
      initMotionControl(motorSamplingPeriod, motorTimeConstant);

/*  Start Multitasking processes                              */
      startProcess(*motionControl);
      startProcess(*sampleSensors);
      startProcess(*avoidBump);
      startProcess(*diffIR);
      startProcess(*migrate);
      startProcess(*debug);

/*  Main Program Loop                                         */
  while(1)
  {

/*   If ir rate is small and there is no bump the robot can migrate       */
     if ((urgentBump == 0)&&(abs(irRate) < 15 ))
     {
     setDesiredTurnRate(migrateRate);
     setDesiredSpeed(irSpeed);
     };

/*   If ir rate is high and there is no bump the robot must use ir rate   */
     if ((urgentBump == 0)&&(abs(irRate) >= 15))
     {
     setDesiredTurnRate(irRate);
     setDesiredSpeed(irSpeed);
     };
  };
}


/*----------------------------------------------------------------------*/
/* Set up interrupt vectors                                  */
/*----------------------------------------------------------------------*/
#include <vectors.c>

/**************************************************************************/
/* Sensor Interface                                   */
/*                                          */
/* Programmer:   Kevin McFarlin                               */
/* Date:         November 20, 1996                        */
/* Version:      1                                  */
/**************************************************************************/

/*----------------------------------------------------------------------*/
/* Includes                                          */
/*----------------------------------------------------------------------*/
  #include <ir.h>
  #include <bump.h>

/*----------------------------------------------------------------------*/
/* Defines                                           */
```

```
/*----------------------------------------------------------------------*/

/* Delay between sensor readings in milliseconds                         */
    #define sensorSampleRate 100

/* IR Sensor Names                                      */
    #define outerLeft 0
    #define innerLeft 1
    #define innerRight 2
    #define outerRight 3
    #define leftWall 4
    #define rightWall 5

/* Bump Sensor Names                                      */
    #define farLeft 0
    #define nearLeft 1
    #define leftCenter 2
    #define rightCenter 3
    #define nearRight 4
    #define farRight 5

/* Turn Names                                      */
    #define right 1
    #define left 0

/*----------------------------------------------------------------------*/
/* Init Sensors Process                                      */
/*----------------------------------------------------------------------*/
void initSensors()
  {
   initIR(6, 90, 128, 100, 0xFF);
   initBump(6);
  }

/*----------------------------------------------------------------------*/
/* Sample Sensors Process                                      */
/*----------------------------------------------------------------------*/
void sampleSensors()
  {
   while(1)
     {
        sampleIR();
        sampleBump();
        delay(sensorSampleRate);
     };
  }



/****************************************************************************/
/*                                                           */
/* Motion Control System                                      */
/*                                                           */
/****************************************************************************/
```

```
/*----------------------------------------------------------------------*/
/* Include files                                         */
/*----------------------------------------------------------------------*/
 #include "motor.c"
 #include <timekeep.h>

/*----------------------------------------------------------------------*/
/* Motion Control Defines                                */
/*----------------------------------------------------------------------*/
 #define left 0
 #define right 1

/*----------------------------------------------------------------------*/
/* Motion Control Private Variables                      */
/*----------------------------------------------------------------------*/
 int desiredSpeed = 0;
 int desiredTurnRate = 0;
 int leftSpeed = 0;
 int rightSpeed = 0;
 int motorDT = 50;
 int motorDV = 10;

/*----------------------------------------------------------------------*/
/* Set motor speed sampling period                       */
/*----------------------------------------------------------------------*/
void setMotorDT(int newDT)
 {
  motorDT = newDT;
 }

/*----------------------------------------------------------------------*/
/* Set increment for changing motor speed                */
/*----------------------------------------------------------------------*/
void setMotorDV(int newDV)
 {
  motorDV = newDV;
 }

/*----------------------------------------------------------------------*/
/* Set desired speed function                            */
/*----------------------------------------------------------------------*/
void setDesiredSpeed(int newSpeed)
 {
  desiredSpeed = newSpeed;
 }

/*----------------------------------------------------------------------*/
/* Set desired turn rate function  (right turn +)        */
/*----------------------------------------------------------------------*/
void setDesiredTurnRate(int newRate)
 {
  desiredTurnRate = newRate;
 }
```

```
/*-----------------------------------------------------------------------*/
/* Get current speed function                                    */
/*-----------------------------------------------------------------------*/
int getDesiredSpeed()
  {
   return desiredSpeed;
  }

/*-----------------------------------------------------------------------*/
/* Get current turn rate function                                */
/*-----------------------------------------------------------------------*/
int getDesiredTurnRate()
  {
   return desiredTurnRate;
  }

/*-----------------------------------------------------------------------*/
/* Initialize Motion Control System                                   */
/*-----------------------------------------------------------------------*/
void initMotionControl()
  {
/*  Initialize Variables                                        */
     desiredSpeed=0;
     desiredTurnRate=0;
     leftSpeed = 0;
     rightSpeed = 0;
     motorDT = 50;
     motorDV = 10;

/*  Initialize the time keeper                                  */
     initTimeKeeper();

/*  Initialize the motors                                       */
     init_motors();

/*  Turn off motors                                             */
     motor(left,0);
     motor(right,0);

  }

/*-----------------------------------------------------------------------*/
/* Motion Control Process                                        */
/*-----------------------------------------------------------------------*/

void motionControl()
  {
/*  Variables                                                   */
     int leftDutyCycle;
     int rightDutyCycle;
     int desiredLeftSpeed;
     int desiredRightSpeed;

/*  Main motion control loop                                      */
     while (1)
```

```
    {

/*    motion control system                                  */
      desiredRightSpeed = desiredSpeed - desiredTurnRate;
      desiredLeftSpeed  = desiredSpeed + desiredTurnRate;

/*    motion smoothing routines - slow response              */
      if (desiredLeftSpeed - leftSpeed > 0)
        leftSpeed += motorDV;
      else if (desiredLeftSpeed - leftSpeed < 0)
        leftSpeed -= motorDV;

      if (desiredRightSpeed - rightSpeed > 0)
        rightSpeed += motorDV;
      else if (desiredRightSpeed - rightSpeed < 0)
        rightSpeed -= motorDV;

/*    motor speed control system  (does nothing yet)         */
      leftDutyCycle  = leftSpeed;
      rightDutyCycle = rightSpeed;

/*    motor driver                                           */
      motor(left,  leftDutyCycle );
      motor(right, rightDutyCycle);

/*    Wait                                                   */
      delay(motorDT);

    };
  }
```