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**Final Report
Automated Storage & Retrieval System**

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I. Abstract

Limited floor space in warehouses can hinder the rate of manufacturer production. An economical solution is to utilize the vertical space with an efficient Automated Storage and Retrieval System (ASRS) that can regulate the flow of incoming and outgoing products. An ASRS intelligently picks up pallets from a transition dock and traverses a path to the storage shelf, where it places the pallet securely onto a three tier shelving system. The process can also be reversed. Through RF communication and IR remote control input, tasks to retrieve pallets off the shelf for delivery can be accepted and executed.

II. Executive Summary

When it comes down to it, humans make mistakes that can prove to be costly (and even deadly) in a warehouse environment. These devastating errors are eliminated by replacing humans with an autonomous agent: the Automated Storage and Retrieval System, dubbed ASRS. The ASRS comes to life by navigating high contrast lines on the warehouse floor. It moves from dock to dock in the process of storing pallets. However, the robust size of the ASRS prevents it from overcoming the warehousing process by itself. The AGV is a small, elite vehicle that is capable of flying through a warehouse at tremendous speeds and feeding the ASRS with pallets. The brain behind the operation is a high speed PIC microcontroller. It uses five senses to operate with a high level of intelligence: line follower , distance, bump, IR remote control, and RF data link. The feedback from individual sensors is compiled in a central processor, which controls the behavior of the robot through fine motor control.

In the crusade to keep warehouse prices down, the ASRS stores an incoming pallet on the first empty shelf it sees, and its memory modules allow it to remember the location and age of the pallet. The multifunctional robot is also capable of shipping pallets out of the warehouse. It delivers the oldest item to the bottom shelf, where the AGV can pick it up and dispose of it at the outgoing dock. In an attempt to install order, the ASRS processes jobs on a first-in, first-out basis. Advanced behaviors allow the ASRS to multitask; it can process incoming requests, traverse the warehouse, and command the AGV all in the same time frame.

III. Introduction

Modern manufactures have shifted their focus from mass production to selective production in small quantities. While this allows for greater control over company resources such as cash capital and raw materials, it puts a large strain on the warehousing division. Companies can no longer rely on large quantities on the shelf to satisfy customer demands, and instead they must move products quickly off of the factory floor and into the shipping department. There are inherent dangers with such a large rush on product movement.

The first and most important risk a business takes is personal injury. Warehouse floors quickly turn into suburban battle grounds as the work day progresses. Although wide isles can accommodate forklifts operating side by side, there is little margin for error. Gone are the days of small, dirt floor warehouses; modern multimillion dollar facilities measure their warehouse floor in acres. Wider aisles have an inverse affect on warehouse utilization. In addition, human error naturally results in products being misplaced, which can add a tremendous overhead to shipping times.

All of these issues are solved with the introduction of an autonomous vehicle, the Automated Storage and Retrieval system. Because the ASRS can quickly and efficiently store pallets in very narrow aisles, costs are kept down by reducing the square acreage of the warehouse. Standard hazards in the warehouse can be avoided with sensory perception. However, the greatest attribute of the ASRS is its lack of direct human contact. It is capable of handling all aspects of the warehouse: including shipping, receiving, and remembering which jobs it has and has not completed. The ASRS will add an immense amount of value to any company's warehousing operation.

IV. Integrated System

A Pic18F8720 microcontroller controls of the functions of the ASRS. The 8720 includes 128kB of programmable memory, 3840B of SRAM, 1kB of EEPROM and has more than enough data ports that will be required for this project. There are 16 10-bit ATD converter channels of which 6 are used for the four line follower sensors and two proximity detectors, 5 PWM channels to control the motor drivers, two UARTs for barcode data transmission and for the RF link, and also two 8-bit timers and 3 16-bit timers. Three of the four external interrupt pins are being used for the IR receiver for remote control input, RF data ready flag, and high priority fork limit switch. Eight NiMH batteries provide 9.6V to power the 5V and 3.3V regulators and the motors.

All of the software was written in C in modular structure and compiled using the MPLab v7 IDE and MPASM. The functions for the motors, LCD, analog to digital converter, navigation, RF data link, and behaviors were coded independently and tested before integration.

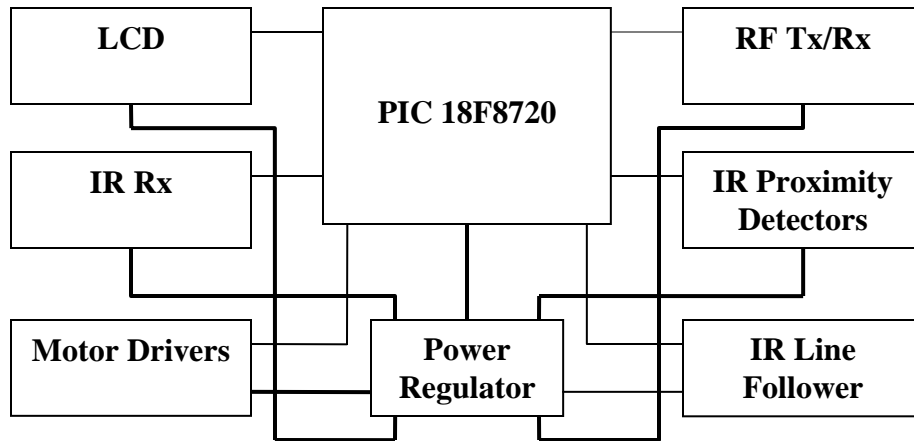


Figure 1 Circuitry Layout

V. Mobile Platform

The circuitry and motors are encased in a durable platform constructed of thin craft plywood. The platform was designed to address a top heavy mass when fully loaded with a pallet. To counter the weight I placed the two motors in the rear, two casters in the front, and the batteries and electronics in the rear compartment. I began with rough sketches the design that I wanted and then drafted a similar design in AutoCAD to be used for the T-Tech.



Figure 2 Mobile Platform

VI. Actuation

i. Drive

The ASRS achieves forward and reverse mobility by using two 200rpm 12V DC gear-head motors to turn dual wheels fitted with 56mm diameter by 24mm wide Tamiya sport tires. The motors were controlled by sending pulse width modulated signals to a JRC Dual H-Bridge (NJM2670). The motor drivers worked fairly well using the implementation provided in their spec sheet. To reduce the number of PWM outputs required to drive three motors, I multiplexed two signals from the first driver to the third and selected which drivers to control by setting the enables.

I implemented a staircase motor smoothing function to reduce the current spikes of switching the motors on and off. This counters the problem of the initial jerk that the ASRS experienced when switching speeds.

One of the problems that I encountered when running the ASRS on the warehouse floor (see plaza.ufl.edu/tskipp/agv_asrs) is that the rough, uneven surface of the plywood causes the ASRS to bounce fairly hard due to the front casters colliding with the edges of the grooves in the wood. This will force the rear tires to carry all of the weight and stall the motors briefly. At times, it will derail the ASRS from the line causing it to lose its current position. This can easily be solved by ensuring that the surface that the robot operates on is as smooth as possible.

ii. Forklift

The forklift is raised and lowered by an additional 200rpm 12V DC gear-head motor turning a 1/2" screw with a pitch size of 13. The screw is 13.5" long and provides up to 12" of vertical movement. The center of the screw was bored out 1/4" in diameter and 3/4" deep in order to attach it to the motor with a set screw. Three quarters of an inch at the opposite end of the screw was milled down to 1/4" diameter to allow it to freely rotate inside a sleeve. With the motor turning at full speed, it took less than a minute to travel 12" on a non greased screw.

VII. Sensors

i. Bump Sensors

Rear bump sensors serve several primitive functions on the ASRS. Two switches were placed on the rear bumper that disables the motors and stops the vehicle when activated. I wired the switches in parallel between ground and a pull up resistor to 3.3V in order to save an I/O pin on my microcontroller. This was suitable for my purposes since the direction that the bump occurs is not important. The switch is polled in software whenever the ASRS is traveling in reverse.

ii. IR Photodetectors

The ASRS uses four OPB745 IR emitter/detector pairs to track a line below the mobile platform. I found that the lowest price for these sensors were at Mouser Electronics (www.mouser.com) for \$3.60 per unit. The OPB745 is composed of an IR LED and a bipolar junction phototransistor whose output is controlled by incoming infrared light entering the base terminal. The best orientation of the device is at around a 15° angle above the surface pivoted on the phototransistor. About an eighth of an inch clearance provides enough space between the lens and the surface to produce accurate results. I observed that that under indoor lighting, a solid white surface would produce a converted analog value around 70 to 130 and a black electrical tape surface would produce a value above 230. The ASRS is able to dynamically calibrate the threshold to determine a line at system startup to adjust for the different environmental conditions.

iii. IR Proximity detectors

Two short-range Sharp GPD2D120 IR distance sensors provide forward path vision. The cheapest place to purchase the sensors is from the Mark III Robot Store (www.junun.org) for \$8.25 each and a cable can be purchased for an extra \$1.10.

I chose the short range sensors rather than the long range GPD2D12 sensors due to the tight spaces that the ASRS will be operating in. I didn't want the robot to be constantly detecting objects in the distance and mistaking the shelving as an obstruction. With the two sensors

facing forward and crossing paths, I concluded that a value of 80 translated to around 4cm (minimum distance detection) and anything above 70 represents an obstacle fairly close to the ASRS. When this threshold is reached, the motors are disabled and the ASRS waits until the path is cleared.

iv. IR Remote Control Receiver

The ASRS uses a Fairchild Semiconductor infrared detector and a Sony television remote control to receive commands from the user. The sensor and implementation is discussed in detail by Trevor Skipp in his Special Sensor Report which can be found at http://plaza.ufl.edu/tskipp/agv_asrs/photo_sensor.htm.

v. RF 2.4 GHz Transceiver

The ASRS uses a Laipac TRF-2.4G RF wireless transceiver to communicate with the AGV. The transceiver uses a Nordic nRF2401 VLSI chip with a 16MHz crystal oscillator and a built in dipole antenna. The benefits of the Laipac transceiver over a standard RF receiver/transmitter pair are the single chip/device operation for bidirectional communication, dual channel operation, hardware Cyclic Redundancy Checksum (CRC) code generation and error checking, and high speed ShockBurst transmission. The latter three are useful for microcontroller application since they free up processing power required to implement a lower level datalink protocol. I purchased two modules from Spark Fun Electronics (www.sparkfun.com) for \$19.95 each along with two breakout boards that were \$0.95 a piece. The transceiver and implementation is discussed in detail in my Special Sensor Report which can be found at http://plaza.ufl.edu/tskipp/agv_asrs/RF.htm.

VIII. Behaviors

i. Navigating & Positioning

The ASRS is capable of traveling from point to point in the warehouse floor and determine its position so long as it maintains on the path. It begins by following closely to the line until it reaches an intersection at which point it will determine which direction to turn in accordance to three variables: direction, current x coordinate, and destination lane. The ASRS portion of warehouse floor is constructed as a grid system, with one center line and five orthogonal lane extensions that lead to the shelving.

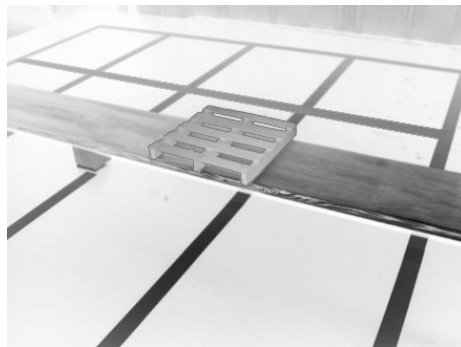


Figure 3 Warehouse Floor & Transition Dock

ii. Communicating

The user can communicate objectives to the ASRS by pressing certain buttons on the remote control. When the channel up button is pressed, it signifies that an incoming pallet has arrived at the incoming dock. In this case the ASRS looks up an empty location on the transition dock and notifies the AGV using the RF data link. The input bit and the transition dock number is sent in the packet. To request a pallet, the channel down button is pressed. The ASRS picks up the next outgoing pallet from the shelf and places it onto the transition dock. When completed, the ASRS will notify the AGV by sending the output bit and the dock number.

iii. Inventory Tracking and Queuing

The ASRS maintains an internal database of the shelves using FIFO inventory. The shelf locations are marked with a 0 if it is empty or a value from 1 to 255 if it is full. Lower values are interpreted as being older pallets that need to exit the warehouse first. The database is scanned whenever an incoming or outgoing request has been made and is changed accordingly whenever pallets enter and leave the shelves.

Up to eight concurrent commands can be sent to the ASRS to be completed through the utilization of a queue stack. This allows the ASRS to finish completing its task before initiating another. It also allows it to wait in idle mode when there are no objectives present.

iv. Storing and Retrieving

The ASRS can store pallets onto different levels using the forklift mechanism discussed under actuation. The different heights are determined by raising or lowering the fork and polling a roller lever switch situated at the height of the shelf behind the fork. This produces very accurate results with no calibration required. Using the switches allows the ASRS to pick up a realistically scaled pallet which has a half inch fork clearance.

IX. Experimental Layout and Results

Each sensor was tested to determine the functionality and operating conditions of the device. The OPB745 line following sensors gave repeatable values under low light conditions. The results for a white and black surface differed enough to interpret the line accurately. Some measurements using the analog to digital converter are given in Table 1.

Left IR	Mid Left IR	Mid Right IR	Right IR
68	77	74	66
70	76	79	68
66	72	75	73
69	81	79	74
192	234	252	207
216	249	243	222
222	244	234	217
209	229	233	230

Table 1 OPB745 Measurements

To test the RF module, I wrote a small routine to increment a counter and send it to another microcontroller without additional error checking protocols. The number of correctly and incorrectly received values were recorded for varying distances. The results are shown below in Table 2. Even at short range operation, the system integrity isn't very high. Several packets were lost during transmission and some random values were also received. This is likely due to the noise in the communication channel caused by several other household devices (802.11, microwaves, cordless phones, etc) operating at the same frequency. The results confirm that a software protocol must be implemented to retransmit lost packets.

Distance (ft)	Number of Missed Packets	Number of Correctly Sent Packets	% Error
3	2	254	0.78125
5	7	249	2.734375
7	2	254	0.78125
9	7	249	2.734375
11	4	252	1.5625

Table 2 RF Experiment Results

IX. Conclusion

The ASRS performs extremely well under low light conditions since it utilizes several various infrared sensors. Under heavy sunlight the IR remote control receiver will pick up short pulses and continuously interrupt the microcontroller and cause it to lock up in the interrupt routine. This was frustrating since it took a lot of time to figure out why it stopped working in the middle of some routines. This can be fixed by using another small microcontroller to handle the IR and send out the received value to the main microcontroller.

Another problem that I encountered was that the ASRS had to be assisted with placing the pallet correctly on the fork. The forks do not extend far enough to support the rear of the pallet, causing the pallet to become unbalanced and tip backward. This can be changed by simply using a longer fork.

Problems also surfaced when I tried to integrate the Stop and Wait ARQ to the RF data link. The software worked independently but did not work in coherence with the other behaviors. I decided to use parity checking with a header attached to the packet which eliminated most of the random packets that were picked up from noise. The source code for the RF Stop and Wait ARQ is included in the CD accompanying this report.

In the end, all the goals set forth by this project were met. The ASRS and AGV operate together better than I had imagined; although the ASRS is a bit slower than I anticipated. Along with the slow ASRS operation, the current warehouse causes the AGV to be underutilized. There are only five transition dock locations that the AGV can manipulate and it fills up too quickly before the ASRS can remove the pallets. The main problem to consider is the forklift mechanism. I think that a pulley system would reduce the travel time of the fork tremendously and speed up the operation.

XI. Sources for Parts

PIC18F8720 Development Board:

www.digikey.com

Price: \$37.00 each

LED Backlit 16x2 LCD Display:

www.junun.org

Price: \$8.50 each

JRC Dual H-Bridge NJM2670

www.mouser.com

Price: \$2.61 each

200RPM 12V Gear-head Motor

www.jameco.com

Price: \$21.95 each

Omni-Directional Metal Casters

www.sparkfun.com

Price: \$4.95/pair

Tamiya 2.2" Sport Tires

www.sparkfun.com

Price: \$5.95/pair

Push Button Switches:

IMDL Lab

Price: Free

Roller Lever Switches:

Radio Shack

Price: \$2.50 each (cheaper at Jameco ~ \$1.25)

OPB745 IR Emitter/Detector Pairs:

www.mouser.com

Price \$3.60 each

Sharp GPD2D12 Distance Measuring Sensors:

www.junun.org

Price: \$8.25 each (+\$1.10 for a cable)

XII. References

Microchip PIC18F8720 Datasheet:

<http://ww1.microchip.com/downloads/en/DeviceDoc/39609b.pdf>

Optek OPB745 Datasheet:

<http://www.optekinc.com/pdf/OPB745.pdf>

JRC Dual H-Bridge NJM2670 Datasheet:

<http://www.njr.co.jp/pdf/bj/bj10021.pdf>

Nordic Semiconductor nRF2401 Datasheet:

http://www.sparkfun.com/datasheets/RF/nRF2401rev1_1.pdf

Sharp GPD2D120 Datasheet:

<http://www.junun.org/MarkIII/datasheets/GP2D120.pdf>

Laipac TRF-2.4G Datasheet:

http://www.sparkfun.com/datasheets/RF/RF-24G_datasheet.pdf

Steven Pickles' Final Report

http://www.mil.ufl.edu/imdl/papers/IMDL_Report_Spring_04/pickles_steven/kirby.pdf

William Dubel's Reliable Line Tracking Report:

<http://www.mil.ufl.edu/imdl/handouts/lt.doc>

XIII. Source Code

```
/* *****  
 * AUTOMATED STORAGE & RETRI EVAL SYSTEM *  
 * * *  
 * EEL5666 Intelligent Machines Design Laboratory *  
 * University of Florida *  
 * Written for the PIC18F8720 @ 20 MHz *  
 * Copyright (2005) Albert Chung 2.12.2005 *  
 * ***** */  
  
#include <p18f8720.h>  
#include <delays.h>  
#include <stdio.h>  
#include "adconv.h"  
#include "bios.h"  
#include "motors.h"  
#include "rf.h"  
#include "interrupts.h"  
#include "nav.h"  
#include "asrs.h"  
  
#pragma config OSC = HS  
#pragma config WDT = OFF  
#pragma config LVP = ON  
#pragma config MODE = MC  
  
#define rear_bump PORTBbits.RB4  
  
void main(void)  
{  
    unsigned char i;  
  
    DDRD = 0x00;  
    DDRB = 0xFF;  
    DDRH = 0x00;  
    DDRC = DDRC & 0b11111011;  
    DDRG = DDRG & 0b11100110;  
    DDRE = DDRE | 0b01111100;  
  
    PWM_Init();  
    Motors(0,0);  
  
    LCD_Init();  
  
    sprintf(message, " :::ASRS::: Press Rear Bump");  
    UPDATE_LCD;  
  
    Init_Fork_Limit_IRQ();  
    Init_RF();  
    Init_IR_IRQ();  
    GLOBAL_IRQ_ON;  
  
    for( i = 0; i < 15; i++ ) // Clear the shelves  
    {  
        shelves[i] = 0;  
    }  
  
    while( rear_bump == 1 )  
    { }  
  
    Calibrate_LF();  
  
    sprintf(message, "Preparing Fork");  
    UPDATE_LCD;  
  
    Initialize_Fork();  
  
    shelves[8] = 1; // preload the pallets on the shelves  
    shelves[7] = 2;  
    shelves[10] = 3;
```

```
shelves[14] = 4;
shelves[11] = 5;

sprintf(message, "...Waiting For Command...");
UPDATE_LCD;

while (1)
{
    if (first != last)
    {
        Move_Pallet();
    }
}

return;
}
```

```

/*****
* AUTOMATED STORAGE & RETRI EVAL SYSTEM
* Behavioral Routines: Storing, Inventory, Queuing
* EEL5666 Intelligent Machines Design Laboratory
* University of Florida
* Written for the PIC18F8720 @ 20 MHz
* Copyright (2005) Albert Chung 2.12.2005
*****/

#include <p18f8720.h>
#include <delays.h>
#include "motors.h"
#include "nav.h"
#include "asrs.h"
#include "bios.h"
#include <stdio.h>

#define tier_1 PORTEbits.RE3 // Active High
#define tier_2 PORTEbits.RE4 // Active Low
#define tier_3 PORTEbits.RE5 // Active Low

// Shelf Location Variables
unsigned char shelves[15] = {0};
unsigned char shelf_num;
unsigned char last_age = 2;
unsigned char first_age = 1;
unsigned char tier_height;
unsigned char IO;
unsigned char last_fork_height; // 0: lower switch limit, 1: tier 1, 2: tier 2, 3: tier 3,
4: upper switch limit

// Queue variables
unsigned char Queue[QUEUE_LENGTH];
signed char first = 0;
signed char last = 0;

/*****
* Move_Pallet: Runs through the steps necessary
* move a pallet across the warehouse floor. Acts
* as an arbitrator for the motors and servo.
*****/

void Move_Pallet(void)
{
    unsigned char packet, IO, temp;

    packet = Queue_Pull();

    if( (packet & 0b00001000) == 0b00001000 ) // Pallet entering the system
    {
        IO = 1;
        shelf_num = packet & 0b00000111;

        sprintf(message, "Picking Up Incoming Pallet");
        UPDATE_LCD;
    }
    else // Pallet leaving the system
    {
        IO = 0; // Get the location of the first pallet to go
        shelf_num = Get_Out_Location();

        sprintf(message, "Picking Up Outgoing Pallet");
        UPDATE_LCD;
    }

    Delay10KTCYx(0);

    Get_Destination(shelf_num); // Set the x coordinate and tier height

    if( (x_dest != x_cur) && (direction == 3) )
    {
        Turn_Around(); // Not already at location and facing the shelves
        Navigate(); // Follow center line until destination lane is reached
    }
    else if ( (direction == 0) || (direction == 2) )
    {
        Navigate(); // Follow center line until destination lane is reached
    }
}

```

```

    }

    sprintf(message, "Positioning ForkTo Tier %d", tier_height);
    UPDATE_LCD;

    Center_Fork_To_Pallet(); // Once arrived at destination, raise or lower fork to the center
of the pallet

    Motors(MF_FORWARD, MF_FORWARD); // Get off the line
    Delay10KTCYx(175);

    Navigate(); // Drive in

    sprintf(message, "Picking Pallet Up ");
    UPDATE_LCD;

    Raise_Fork(); // Lift pallet above shelf

    shelves[shelf_num] = 0;

    Back_Up(); // Drive out

    sprintf(message, "Positioning ForkTo Tier %d", tier_height);
    UPDATE_LCD;

    Center_Fork_To_Pallet(); // Lower the fork

// go to second set of (x,y) coordinates

    if( I0 == 1 ) // Pallet entering the system
    { // Go to the shelves second
        shelf_num = Get_In_Location(); // Find an empty location on shelf to place pallet
    }
    else // Pallet leaving the system
    { // Go to dock second
        shelf_num = Get_Dock_Location(); // Find an empty location on dock to place pallet
    }

    Get_Destination(shelf_num); // Set the x coordinate and tier height

    if( (x_dest != x_cur) ) // Already at location
    {
        Turn_Around();
        Navigate(); // Follow center line until destination lane is reached
    }

    sprintf(message, "Positioning ForkTo Tier %d", tier_height);
    UPDATE_LCD;

    Center_Fork_To_Pallet(); // once arrived, raise or lower fork to the tier

    Raise_Fork(); // Lift pallet above shelf

    Motors(MF_FORWARD, MF_FORWARD); // Get off the line
    Delay10KTCYx(175);

    Navigate(); // Drive in

    Center_Fork_To_Pallet(); // Lower pallet onto shelf

// if outgoing, tell agv to pick up the pallet
    if( I0 == 0 ) // Pallet leaving the system
    {
        sprintf(message, "Requesting AGV Pickup");
        UPDATE_LCD;

        Transmit(shelf_num); // send shelf number where the output resides to the AGV
    }

    Back_Up();

    sprintf(message, "Mission Complete");
    UPDATE_LCD;

    Delay10KTCYx(0);

    sprintf(message, "...Waiting For Command...");
    UPDATE_LCD;

    return;
}

```

```

/*****
* Queue_Pull: Pull a request off of the queue. *
*****/

unsigned char Queue_Pull(void)
{
    unsigned char temp;

    temp = Queue[first];

    first++;

    if( first == QUEUE_LENGTH )
    {
        first = 0;
    }

    return temp;
}

/*****
* Queue_Push: Push a request onto the queue. *
*****/

void Queue_Push(unsigned char packet)
{
    Queue[last] = packet;

    last++;

    if( last == QUEUE_LENGTH )
    {
        last = 0;
    }

    return;
}

/*****
* Get_Destination: Extracts the x destinations *
* and the tier height from the data packet *
*****/

void Get_Destination(unsigned char shelf_num)
{
    // set destination x coordinate and tier height
    if( shelf_num < 5 )
    {
        tier_height = 1;
        x_dest = shelf_num;
    }
    else if( shelf_num < 10 )
    {
        tier_height = 2;
        x_dest = shelf_num - 5;           // Offset of 5
    }
    else // shelf_num < 15
    {
        tier_height = 3;
        x_dest = shelf_num - 10;
    }

    return;
}

/*****
* Get_Dock_Location: Finds and returns an empty *
* location on the transition dock. *
*****/

unsigned char Get_Dock_Location(void)
{
    unsigned char i;

    for( i = 0; i < 5; i++ )
    {
        if( shelves[i] == 0 )
        {
            shelves[i] = 1;           // Mark as full
            return i;
        }
    }
}

```

```

    }
    return;
}

/*****
* Get_In_Location: Finds and returns an empty
* location on the shelves.
*****/

unsigned char Get_In_Location(void)
{
    unsigned char i;

    for (i = 5; i < 15; i++)
    {
        if (shelves[i] == 0) // Location is empty
        {
            shelves[i] = last_age;
            last_age++;
            return i;
        }
    }

    return;
}

/*****
* Get_Out_Location: Finds and returns the
* location of the oldest product on the shelves.
*****/

unsigned char Get_Out_Location(void)
{
    unsigned char i;

    for (i = 5; i < 15; i++)
    {
        if (shelves[i] == first_age) // Oldest product = first to go
        {
            shelves[i] = 0; // Empty the the location
            first_age++;
            return i;
        }
    }

    return;
}

/*****
* Initialize_Fork: Initializes the fork to a
* known state/height.
*****/

void Initialize_Fork(void)
{
    unsigned char temp, temp2 = 0;

    Fork(UP); // Raise fork

    for( temp = 0; temp < 25; temp++ ) // Delay half a second
    {
        if( tier_1 == 1 || tier_2 == 0 || tier_3 == 0 )
        {
            Fork(STOP);
        }

        Delay1KTCYx(0);
    }

    Fork(DOWN); // Lower fork

    while( temp2 == 0 ) // Wait for fork to press a switch
    {
        if( tier_1 == 1 ) // Active High

```

```

    {
        Delay1KTCYx(100);          // Delay 20msec to debounce switch
        while( tier_1 == 1 ) // Wait for fork to get off the switch (active high)
        { }
        Fork(STOP);                // Stop fork
        last_fork_height = 1;
        temp2 = 1;
    }
else if( tier_2 == 0 )           // Active Low
{
    Delay1KTCYx(100);          // Delay 20msec to debounce switch
    while( tier_2 == 0 ) // Wait for fork to get off the switch (active high)
    { }
    Fork(STOP);                // Stop fork
    last_fork_height = 2;
    temp2 = 1;
}
else if( tier_3 == 0 )           // Active Low
{
    Delay1KTCYx(100);          // Delay 20msec to debounce switch
    while( tier_3 == 0 ) // Wait for fork to get off the switch (active high)
    { }
    Fork(STOP);                // Stop fork
    last_fork_height = 3;
    temp2 = 1;
}
}

sprintf(message, "Fork initialized to tier %d", last_fork_height);
UPDATE_LCD;

Delay10KTCYx(0);
Delay10KTCYx(0);
Delay10KTCYx(0);

return;
}

void Center_Fork_To_Pallet(void)
{
    switch(tier_height)
    {
        case 1:
        {
            if( last_fork_height > 1 )
            {
                Fork(DOWN);          // Lower fork
                while( tier_1 != 1 ) // Wait for fork to press the switch (active high)
                { }
                Delay1KTCYx(100);    // Delay 20msec to debounce switch
                while( tier_1 == 1 ) // Wait for fork to get off the switch (active high)
                { }
            }
            Fork(STOP);                // Stop fork
            last_fork_height = 1;
            break;
        }
        case 2:
        {
            if( last_fork_height > 2 )
            {
                Fork(DOWN);          // Lower fork
                while( tier_2 != 0 ) // Wait for fork to press the switch

```

```

        { }
        Delay1KTCYx(100); // Delay 20msec to debounce switch
        while( tier_2 == 0 ) // Wait for fork to get off the switch
        { }
    }
    else if( last_fork_height < 2 )
    {
        Fork(UP); // Raise fork

        while( tier_2 != 0 )
        { }
    }

    Fork(STOP); // Stop fork

    last_fork_height = 2;
    break;
}
case 3:
{
    if( last_fork_height > 3 )
    {
        Fork(DOWN); // Lower fork

        while( tier_3 != 0 ) // Wait for fork to press the switch
        { }

        Delay1KTCYx(100); // Delay 20msec to debounce switch

        while( tier_3 == 0 ) // Wait for fork to get off the switch
        { }
    }
    else if( last_fork_height < 3 )
    {
        Fork(UP); // Raise fork

        while( tier_3 != 0 ) // Wait for fork to press switch
        { }
    }

    Fork(STOP); // Stop fork

    last_fork_height = 3;
    break;
}
}

Fork(UP);
Delay10KTCYx(175);
Fork(STOP);

return;
}

/*****
* Raise_Fork: Raises the fork
*****/

void Raise_Fork(void)
{
    unsigned char i;

    last_fork_height = 4;

    Fork(UP);

    Delay10KTCYx(0); // Raise fork for 3 seconds
    Delay10KTCYx(0);
    Delay10KTCYx(0);
    Delay10KTCYx(0);
    Delay10KTCYx(0);
    Delay10KTCYx(0);
    Delay10KTCYx(0);

    Fork(0); // Stop the fork

    return;
}

```

```

/*****
 * HITACHI LCD CONTROLLER
 *
 * Written for the PIC18F8720 @ 20 MHz
 * Interfaces: Enable on RDO, RS on RD1, DB4:7 on
 * RD4:7
 * Copyright 2005 Albert Chung & Trevor Skipp
 *****/

#include <p18f8720.h>
#include <delays.h>
#include "bios.h"

#define lcdport PORTD
#define EN PORTDbits.RD0
#define RS PORTDbits.RD1

void LCD_Init(void);
void LCD_En(void);
void LCD_Write(char data);
void LCD_Command(int);
void Update_LCD(void);

char message[40];

/*****
 * printLCD: Sends a string one character at a time
 * to LCD_Write.
 *****/

void Update_LCD(void)
{
    int i, j;

    LCD_Command(0x01);           // Clear display & return cursor home
    Delay10KTCYx(5);           // 5 msec

    for(i = 0; i < 32; i++)
    {
        if ( message[i] == '\0' )
        {
            break;
        }

        if (i == 16)
        {
            for(j = 0; j < 24; j++)
            {
                LCD_Write(' ');
            }

            LCD_Write(message[i]);
        }

        else
        {
            LCD_Write(message[i]);
        }
    }

    return;
}

/*****
 * LCD_En: Enables the LCD. This tells the LCD to
 * read in data.
 *****/
void LCD_En(void)
{
    Delay10TCYx(100);           // 50 usec
    EN = 1;                     // PORTDbits.RD0 = 1
    Delay10TCYx(100);           // 50 usec
    EN = 0;                     // PORTDbits.RD0 = 0
    Delay10TCYx(100);           // 50 usec

    return;
}

```

```

/*****
 * LCD_Init: Initializes the LCD for 4 bit mode,
 * 2 lines, 5x11 dot matrix, display on, cursor
 * off, blink off, clear screen, return cursor
 * home, increment cursor to the right, and don't
 * shift the screen.
 *****/
void LCD_Init(void)
{
    int i;
    int setup[] = {0x33, 0x32, 0x2C, 0x0C, 0x01, 0x06};

    Delay10KTCYx(40); // 20 msec power up

    for (i = 0; i < 6; i++)
    {
        LCD_Command(setup[i]);
        Delay10KTCYx(10); // 5 msec
    }

    return;
}

/*****
 * LCD_Command: Modify data to set RS (Register
 * Select) to command mode. Sends data to the LCD.
 *****/
void LCD_Command(int command)
{
    int temp;

    RS = 0; // PORTDbits.RD1 = 0

    temp = command & 0xF0; // Mask off lower nibble
    lcdport &= 0x0F; // Clear upper nibble
    lcdport |= temp;
    LCD_En();

    Delay10TCYx(110); // 55 usec

    temp = command << 4;
    temp &= 0xF0; // Clear upper nibble
    lcdport &= 0x0F;
    lcdport |= temp;
    LCD_En();

    return;
}

/*****
 * LCD_Write: Reads in the argument and displays it
 * on the LCD.
 *****/
void LCD_Write(char data)
{
    int temp;

    RS = 1; // PORTDbits.RD1 = 1

    temp = data & 0xF0; // Mask off lower nibble
    lcdport &= 0x0F; // Clear upper nibble
    lcdport |= temp;
    LCD_En();

    Delay10TCYx(110); // 55 usec

    temp = data << 4;
    temp &= 0xF0; // Clear upper nibble
    lcdport &= 0x0F;
    lcdport |= temp;
    LCD_En();

    return;
}

```

```

/*****
 * ANALOG TO DIGITAL CONVERSION
 *
 * Written for the PIC18F8720 @ 20 MHz
 * Interfaces: Analog inputs on AN0:5
 * Copyright 2005 Trevor Skipp
 *
 * NOTES:
 * The following code is for 8 analog channels, and
 * the remaining pins are set to digital I/O. If
 * more analog channels are desired, adjust
 * ADCON1 in each function, and follow the
 * pattern in the functions.
 * A delay is required before a subsequent sample.
 * This is the delay before the return statement
 * in each function. This delay could be moved
 * or eliminated (i.e. you will not be taking
 * samples back to back) to free up processor
 * cycles.
 *****/

#include <p18f8720.h>
#include <delays.h>
#include "adconv.h"

int Read_AD0();
int Read_AD1();
int Read_AD2();
int Read_AD3();
int Read_AD4();
int Read_AD5();
void Poll_AD_Done(void);

// Following declarations
int black_l, black_ml, black_mr, black_r;
int line_data;
int prev_line_data;

/*****
 * Poll_AD_Done: Poll until the conversion is
 * complete.
 *****/
void Poll_AD_Done(void)
{
    for(;;)
    {
        if (ADCON0 & 0b00000001 == 0b00000001)
        {
            return;
        }
    }
}

/*****
 * Read_ADx: Select "x" analog channel and sample
 * it. Returns the 8 bit value of the analog
 * channel.
 *****/
int Read_AD0(void)
{
    ADCON1 = 0b00000111; //Vref+ = External Vref + (5V to pin 27), Vref- = Vss, AN0:5 analog
    in, AN6: 15 digital I/O (PAGE 214)

    ADCON0 = 0b00000000; //select AD0, set "GO", and ADON off (PAGE 213)

    ADCON2 = 0b00000010; //left justify, conversion time = 64 * Tosc (PAGE 215)
    ADCON0 = 0b00000001; //turn on A/D module

    Delay10TCYx(13); //6.5us

    ADCON0 = 0b00000011; //GO

    Poll_AD_Done();

    Delay10TCYx(35); //23us

    return ADRESH;
}

int Read_AD1(void)
{

```

```

        ADCON1 = 0b00000111; //Vref+ = External Vref + (5V to pin 27), Vref- = Vss, AN0:5 analog
in, AN6: 15 digital I/O (PAGE 214)

        ADCON0 = 0b00000100; //select AD1, set "G0", and ADON off (PAGE 213)

        ADCON2 = 0b00000010; //left justify, conversion time = 64 * TOSC (PAGE 215)
        ADCON0 = 0b00000101; //turn on A/D module

        Delay10TCYx(13); //6.5us

        ADCON0 = 0b00000111; //G0

        Poll_AD_Done();

        Delay10TCYx(35); //23us

        return ADRESH;
}

int Read_AD2(void)
{
        ADCON1 = 0b00000111; //Vref+ = External Vref + (5V to pin 27), Vref- = Vss, AN0:5 analog
in, AN6: 15 digital I/O (PAGE 214)

        ADCON0 = 0b00001000; //select AD2, set "G0", and ADON off (PAGE 213)

        ADCON2 = 0b00000010; //left justify, conversion time = 64 * TOSC (PAGE 215)
        ADCON0 = 0b00001001; //turn on A/D module

        Delay10TCYx(13); //6.5us

        ADCON0 = 0b00001011; //G0

        Poll_AD_Done();

        Delay10TCYx(35); //23us

        return ADRESH;
}

int Read_AD3(void)
{
        ADCON1 = 0b00000111; //Vref+ = External Vref + (5V to pin 27), Vref- = Vss, AN0:5 analog
in, AN6: 15 digital I/O (PAGE 214)

        ADCON0 = 0b00001100; //select AD3, set "G0", and ADON off (PAGE 213)

        ADCON2 = 0b00000010; //left justify, conversion time = 64 * TOSC (PAGE 215)
        ADCON0 = 0b00001101; //turn on A/D module

        Delay10TCYx(13); //6.5us

        ADCON0 = 0b00001111; //G0

        Poll_AD_Done();

        Delay10TCYx(35); //23us

        return ADRESH;
}

int Read_AD4(void)
{
        ADCON1 = 0b00000111; //Vref+ = External Vref + (5V to pin 27), Vref- = Vss, AN0:5 analog
in, AN6: 15 digital I/O (PAGE 214)

        ADCON0 = 0b00010000; //select AD4, set "G0", and ADON off (PAGE 213)

        ADCON2 = 0b00000010; //left justify, conversion time = 64 * TOSC (PAGE 215)
        ADCON0 = 0b00010001; //turn on A/D module

        Delay10TCYx(13); //6.5 us

        ADCON0 = 0b00010011; //G0

        Poll_AD_Done();

        Delay10TCYx(35); //23us

        return ADRESH;
}

```

```

int Read_AD5(void)
{
    ADCON1 = 0b00000111; //Vref+ = External Vref + (5V to pin 27), Vref- = Vss, AN0:5 analog
    in, AN6: 15 digital I/O (PAGE 214)
    ADCON0 = 0b00010100; //select AD5, set "GO", and ADON off (PAGE 213)
    ADCON2 = 0b00000010; //left justify, conversion time = 64 * TOSC (PAGE 215)
    ADCON0 = 0b00010101; //turn on A/D module
    Delay10TCYx(13); //6.5us
    ADCON0 = 0b00010111; //GO
    Poll_AD_Done();
    Delay10TCYx(35); //23us
    return ADRESH;
}

int Read_AD6(void)
{
    ADCON1 = 0b00000111; //Vref+ = External Vref + (5V to pin 27), Vref- = Vss, AN0:5 analog
    in, AN6: 15 digital I/O (PAGE 214)
    ADCON0 = 0b00011000; //select AD6, set "GO", and ADON off (PAGE 213)
    ADCON2 = 0b00000010; //left justify, conversion time = 64 * TOSC (PAGE 215)
    ADCON0 = 0b00011001; //turn on A/D module
    Delay10TCYx(13); //6.5us
    ADCON0 = 0b00011011; //GO
    Poll_AD_Done();
    Delay10TCYx(35); //23us
    return ADRESH;
}

int Read_AD7(void)
{
    ADCON1 = 0b00000111; //Vref+ = External Vref + (5V to pin 27), Vref- = Vss, AN0:5 analog
    in, AN6: 15 digital I/O (PAGE 214)
    ADCON0 = 0b00011100; //select AD7, set "GO", and ADON off (PAGE 213)
    ADCON2 = 0b00000010; //left justify, conversion time = 64 * TOSC (PAGE 215)
    ADCON0 = 0b00011101; //turn on A/D module
    Delay10TCYx(13); //6.5us
    ADCON0 = 0b00011111; //GO
    Poll_AD_Done();
    Delay10TCYx(35); //23us
    return ADRESH;
}

```

```

/*****
 * Interrupt Polling
 *
 * Written for the PIC18F8720
 * Interfaces:
 * High Priority interrupts: INT0 -> Lower Fork Limit
 *                               INT3 -> Upper Fork Limit
 * Low Priority interrupts:  INT1 -> TRF-24G RD1
 *                               INT2 -> Rear Bump switches
 *                               (falling edge)
 *
 * Credits: Microchip
 * Written by Albert Chung & Trevor Skipp
 *****/

#include <p18f8720.h>
#include <stdio.h>
#include "rf.h"
#include "bios.h"
#include "motors.h"
#include "interrupts.h"
#include "asrs.h"

#define driver2_en    PORTDbits.RD3

void low_isr(void);
void high_isr(void);
void InitInt(void);
void Disable_TMR0_IRQ(void);
void Init_TMR1_Overflow_IRQ(void);

// RF Stop and Wait ARQ
#define TIMEOUT_SIZE 3
unsigned char timeout_ctr = 0;
unsigned char num_timeouts = 0;

int my_count;

// IR Detector variables
unsigned char count;
unsigned char data[5];
unsigned char remote;
unsigned char num_overflows;
unsigned char skip = 5; // Used to skip the first 5 IR samples on startup, subsequent IR samples must
skip 6
unsigned char manual_mode = 0;

int forward = 100;
int reverse = -100;

/*****
 * For PIC18 devices the low interrupt vector is found at
 * 0000018h. The following code will branch to the
 * low_interrupt_service_routine function to handle
 * interrupts that occur at the low vector.
 *****/

#pragma code low_vector=0x18
void interrupt_at_low_vector(void)
{
    _asm GOTO low_isr _endasm
}
#pragma code /* return to the default code section */

#pragma interruptlow low_isr
void low_isr (void)
{
    int ir_watchdog = 0;
    unsigned char temp1, temp2;

    if ( INTCON3bits.INT2IF == 1) // IR triggered interrupt
    {

        T3CON = 0b00000001;

        // Skip the first 5 samples
        for(count = 0; count < 5; count++)
        {

```

```

        while (PORTBbits.RB2 == 0)           //wait for rising edge
        {}

        while (PORTBbits.RB2 == 1)           //wait for falling edge
        {}
    }

    // Grab the length of the next 5 high pulses
    for(count = 0; count < 5; count++)
    {
        TMR3H = 0x00;
        TMR3L = 0x00;

        while (PORTBbits.RB2 == 0)           //wait for rising edge
        {}

        while (PORTBbits.RB2 == 1)           //wait for falling edge
        {}

        if (TMR3H > 20)
        {
            data[count] = 1;
        }
        else
        {
            data[count] = 0;
        }
    }

    if (skip == 5)
    {
        skip = 6;
    }

    // Convert data[] into an integer
    count = 0;
    remote = 0;

    if (data[count++] == 1)
    {
        remote |= 0b00001;
    }
    if (data[count++] == 1)
    {
        remote |= 0b00010;
    }
    if (data[count++] == 1)
    {
        remote |= 0b00100;
    }
    if (data[count++] == 1)
    {
        remote |= 0b01000;
    }
    if (data[count] == 1)
    {
        remote |= 0b10000;
    }

    // "remote" now contains the hex code for the remote button
    if( remote == 17 )           // Channel Up ( package entering system )
    {
        temp1 = Get_Dock_Location();
        temp2 = temp1 | 0b00001000;
        Transmit(temp2);

        sprintf(message, "Incoming Request Sent To AGV");
        UPDATE_LCD;
    }
    else if( remote == 18 )     // Channel Down ( package leaving system )
    {
        Queue_Push(0b00000111);

        sprintf(message, "Outgoing Request Placed On Queue");
        UPDATE_LCD;
    }
}

```

```

        Delay10KTCYx(0);
        Delay10KTCYx(0);
    }
    INTCN3bits.INT2IF = 0; // Clear INT2 flag
}
if ( INTCN3bits.INT1IF == 1) // RF Rx data ready
{
    Receive();
    INTCN3bits.INT1IF = 0; // Clear the INT1 Flag
}
if (INTCONbits.TMROIF == 1) // TMRO overflowed (no ACK received)
{
    if( num_timeouts == 3 )
    {
        if( timeout_ctr < TIMEOUT_SIZE )
        {
            Disable_TMRO_IRQ();
            Transmit(tx_buffer); // Other terminal missed the packet / resend
            timeout_ctr++;
        }
        else // Give up sending data
        {
            Disable_TMRO_IRQ();
            timeout_ctr = 0;
        }
        num_timeouts = 0;
    }
    num_timeouts++;
    INTCNbits.TMROIF = 0; // Clear the TMRO overflow Flag
}
}

/*****
* For PIC18 devices the high interrupt vector is found at
* 00000008h. The following code will branch to the
* high_interrupt_service_routine function to handle
* interrupts that occur at the high vector.
*****/

#pragma code high_vector=0x08
void interrupt_at_high_vector(void)
{
    _asm GOTO high_isr _endasm
}
#pragma code /* return to the default code section */

#pragma interrupt high_isr
void high_isr (void)
{
    if ( PIR2bits.TMR3IF == 1) // Timer 3 overflowed
    {
        if (++num_overflows == 30)
        {
            INTCN3bits.INT2IE = 1; // Enable INT1 XIRQ
            PIE2bits.TMR3IE = 0; // Disable interrupt
            num_overflows = 0;
        }
        PIR2bits.TMR3IF = 0; // Clear flag
    }
    if ( PIR2bits.CCP2IF == 1) // Capture pin triggered
    {
        // ...
        PIR2bits.CCP2IF = 0; // Clear the INTO Flag
    }
    if ( PIR1bits.TMR1IF == 0) // Timer 1 overflowed
    {
        // ...
        PIR1bits.TMR1IF = 0;
    }
    if ( INTCNbits.INT0IF == 1) // Fork limit reached
    {

```

```

        Fork(STOP);                // Stop the fork
        driver2_en = 0;            // Di sable the fork motor driver
        sprintf(message, "Fork Li mi t Reached!");
        UPDATE_LCD;

        INTCONbits.INTOIF = 0;     // Clear the INTO Flag
        while(1)                   // Do nothing until reset
        {
    }
}

/*****
* Initialize interrupts
*****/

void Ini t_Gl obal_I RQ(void)
{
    RCONbits.IPEN = 1;             // Enable interrupt priority
    INTCONbits.GIEH = 1;          // Enable all high priority interrupts
    INTCONbits.GIEL = 1;          // Enable all low priority interrupts

    return;
}

void Di sabl e_Gl obal_I RQ(void)
{
    INTCONbits.GIEH = 0;          // Enable all high priority interrupts
    INTCONbits.GIEL = 0;          // Enable all low priority interrupts

    return;
}

void Ini t_TMR3_Overfl ow_I RQ(void)
{
    IPR2bits.TMR3IP = 1;         // High priority
    PIR2bits.TMR3IF = 0;         // Clear flag
    PIE2bits.TMR3IE = 1;         // Enable interrupt

    return;
}

void Ini t_RF_I RQ(void)
{
    INTCON2bits.INTEDG1 = 1;      // INT1 = rising edge interrupt
    INTCON3bits.INT1IP = 0;      // INT1 = low priority interrupt
    INTCON3bits.INT1IF = 0;      // Clear the INT1 Flag
    INTCON3bits.INT1IE = 1;      // Enable INT1 XIRQ

    return;
}

void Di sabl e_RF_I RQ(void)
{
    INTCON3bits.INT1IE = 0;       // Di sabl e INT1 XIRQ

    return;
}

void Ini t_TMRO_I RQ(void)
{
    INTCON2bits.TMROIP = 0;       // TMRO = low priority interrupt
    INTCONbits.TMROIF = 0;       // Clear the TMRO overflow Flag

// 400 ms timer flag
    TOCON = 0b10000101;         // Timer0 on, 16 bit, instruction clk (5MHz), low to high
                                // transition increment, prescale on, 5MHz/64
    TMROH = 0;                  // Clear the Timer
    TMROL = 0;

    INTCONbits.TMROIE = 1;       // Enable TMRO overflow IRQ

    return;
}

```

```

void Disable_TMRO_IRQ(void)
{
    TOCON = 0; // Turn off the timer
    INTCONbits.TMROIE = 0; // Disable TMRO overflow IRQ

    return;
}

void Init_IR_IRQ(void)
{
    INTCON2bits.INTEDG2 = 0; // INT2 = falling edge interrupt
    INTCON3bits.INT2IP = 0; // INT2 = low priority interrupt
    INTCON3bits.INT2IF = 0; // Clear the INT2 Flag
    INTCON3bits.INT2IE = 1; // Enable INT2 XIRQ

    // Configure Timer1 which is used in subroutine

    T1CON = 0b00000001;

    return;
}

void Init_Fork_Limit_IRQ(void)
{
    INTCON2bits.INTEDG0 = 0; // INTO = falling edge interrupt
    INTCONbits.INTOIF = 0; // Clear the INTO flag
    INTCONbits.INTOIE = 1; // Enable INTO XIRQ

    return;
}

```

```

/*****
 * MOTOR CONTROLLER
 *
 * Written for the PIC18F8720 @ 20 MHz
 * Interfaces: Digital outputs on CCP1, 3, 4, 5 that
 * connect to a JRC Dual H-Bridge NJM2670.
 * Copyright (2005) Trevor Skipp & Albert Chung
 *
 * NOTES:
 * The PWM output pins CCP1, 3, 4, 5 must be set to
 * outputs in the main function.
 *   DDRC = DDRC & 0b11111011;
 *   DDRG = DDRC & 0b11100110;
 * 8 bit resolution
 * The JRC chip uses 2 PWM inputs to control each
 * motor. No direction pin is used.
 * CCP1: Left motor (-) / Fork motor (+)
 * CCP3: Left motor (+) / Fork motor (-)
 * CCP4: Right motor (+)
 * CCP5: Right motor (-)
 * RD2: Motor Driver 1 Enable
 * RD3: Motor Driver 2 Enable
 *****/

#include <p18f8720.h>
#include <delays.h>
#include "interrupts.h"
#include "bios.h"
#include <stdio.h>

#define driver1_en PORTDbits.RD2
#define driver2_en PORTDbits.RD3
#define lower_fork_limit PORTEbits.RE2
#define upper_fork_limit PORTEbits.RE6
#define step_size 5

int left_old_speed = 0;
int left_new_speed = 0;

int right_old_speed = 0;
int right_new_speed = 0;

unsigned char fork_direction;

/*****
 * PWM_Init: Initialize the PWM module for 4 DC *
 * motors using Timer 2 and 1 servo using Timer 1. *
 *****/

void PWM_Init(void)
{
    PR2 = 0xFF; //Period

    CCPR1L = 0; //Duty cycle = 0
    CCPR3L = 0;
    CCPR4L = 0;
    CCPR5L = 0;

    T2CON = 0b0000101; //Timer 2: no postscale, module on, and 4 prescaler

    CCP1CON = 0b00001100; //PWM mode and Duty cycle's LSB1:0 = 0
    CCP3CON = 0b00001100;
    CCP4CON = 0b00001100;
    CCP5CON = 0b00001100;

    return;
}

/*****
 * Fork: Raise or lower the fork.
 *****/

void Fork(signed char direction)
{
    fork_direction = direction;

    driver1_en = 0;
    driver2_en = 1;

    if (direction == 1) //Full Up 100%

```

```

    {
        CCPR1L = 0b11111111;
        CCPR3L = 0;
    }
else if (direction == 0)           //Stop
{
    CCPR1L = 0;
    CCPR3L = 0;
}
else if (direction == -1)         //Full Down 100%
{
    CCPR1L = 0;
    CCPR3L = 0b11111111;
}

return;
}

/*****
* Motors: Adjust the DC motor speed. Implement
* a smoothing function to improve driving.
*****/

void Motors(int left_desired_speed, int right_desired_speed)
{
    int i = 1;

    driver1_en = 1;
    driver2_en = 0;

    while( (left_new_speed != left_desired_speed) || (right_new_speed != right_desired_speed) )
    {
        if (left_desired_speed > left_old_speed)
        {
            left_new_speed = left_old_speed + step_size;
        }
        else if (left_desired_speed < left_old_speed )
        {
            left_new_speed = left_old_speed - step_size;
        }

        if( right_desired_speed > right_old_speed )
        {
            right_new_speed = right_old_speed + step_size;
        }
        else if( right_desired_speed < right_old_speed )
        {
            right_new_speed = right_old_speed - step_size;
        }

        if ( left_new_speed >= 0 )
        {
            CCPR1L = left_new_speed;           // left motor forward
            CCPR3L = 0;
        }
        else
        {
            CCPR3L = -1*left_new_speed;       // left motor reverse
            CCPR1L = 0;
        }

        if ( right_new_speed >= 0 )
        {
            CCPR4L = right_new_speed;         // right motor forward
            CCPR5L = 0;
        }
        else
        {
            CCPR5L = -1*right_new_speed;     // right motor reverse
            CCPR4L = 0;
        }

        left_old_speed = left_new_speed;
        right_old_speed = right_new_speed;

        Delay10TCYx(1);
    }

    return;
}

```

```

/*****
 * LINE FOLLOWING
 *
 * Written for the PIC18F8720 @ 20 MHz
 * Interfaces: Digital I/O on RHO, RH1, RH2, RH3,
 * and INT1, that connect to a TRF-24G RF module
 * Copyright 2005 Albert Chung and Trevor Skipp
 *
 * NOTES:
 * Hardware Connections:
 * LEFT_IR: AN4
 * MID_LEFT_IR: AN5
 * MID_RIGHT_IR: AN6
 * RIGHT_IR: AN7
 *****/

#include <p18f8720.h>
#include <delays.h>
#include "adconv.h"
#include "motors.h"
#include "asrs.h"
#include "bios.h"
#include <stdio.h>

#define DIST_THRESHOLD 255
#define LINE_THRESHOLD 45

#define rear_bump PORTBbits.RB4
#define TURN_TIME 240

// Line Following declarations
//int black_l, black_ml, black_mr, black_r;
//int line_data;
//int prev_line_data;
// Placed in adconv.h due to errors with memory being overwritten

int rd_l, rd_ml, rd_mr, rd_r;

// Mapping Declarations
unsigned char x_dest;
unsigned char x_cur = 0xFF;
signed char direction = 0;

unsigned char Map_Intersection(void);

/*****
 * Calibrate_LF: IR sensors in line follower can be
 * affected by ambient light. This function
 * allows for the dynamic calibration of the
 * line follower module.
 *****/
void Calibrate_LF (void)
{
    int i;
    int LEFT_RD[3];
    int MID_LEFT_RD[3];
    int MID_RIGHT_RD[3];
    int RIGHT_RD[3];

    for (i = 0; i < 3; i++)
    {
        LEFT_RD[i] = LEFT_IR;
        MID_LEFT_RD[i] = MID_LEFT_IR;
        MID_RIGHT_RD[i] = MID_RIGHT_IR;
        RIGHT_RD[i] = RIGHT_IR;
        Delay1KTCYx(0);
    }

    black_l = (LEFT_RD[0] + LEFT_RD[1] + LEFT_RD[2]) / 3;
    black_ml = (MID_LEFT_RD[0] + MID_LEFT_RD[1] + MID_LEFT_RD[2]) / 3;
    black_mr = (MID_RIGHT_RD[0] + MID_RIGHT_RD[1] + MID_RIGHT_RD[2]) / 3;
    black_r = (RIGHT_RD[0] + RIGHT_RD[1] + RIGHT_RD[2]) / 3;

    black_l += LINE_THRESHOLD;
    black_ml += LINE_THRESHOLD;
    black_mr += LINE_THRESHOLD;
    black_r += LINE_THRESHOLD;

    sprintf(message, "%3d %3d %3d %3d", black_l, black_ml, black_mr, black_r);
    UPDATE_LCD;
}

```

```

        Delay10KTCYx(0);
    }
    return;
}

/*****
 * Read_IR: Reads the IR line following sensors and
 *           converts the array into an integer
 *****/
unsigned char Read_IR (void)
{
    line_data = 0x00;
    if (LEFT_IR < black_l)
    {
        line_data |= 0b1000;
    }
    if (MID_LEFT_IR < black_ml)
    {
        line_data |= 0b0100;
    }
    if (MID_RIGHT_IR < black_mr)
    {
        line_data |= 0b0010;
    }
    if (RIGHT_IR < black_r)
    {
        line_data |= 0b0001;
    }
    return;
}

/*****
 * Turn_Left: Sets motors and delays processor so the
 *            vehicle can get off of the current line and
 *            begin polling for the next line.
 *****/
void Turn_Left(void)
{
    direction++;
    if( direction > 3)
    {
        direction = 0;
    }

    Motors(MF_FORWARD, MF_FORWARD); // Move forward before turning to center rear wheels
on the line
    Delay10KTCYx(TURN_TIME);

    Motors(M_REVERSE, M_FORWARD);
    Delay10KTCYx(175);

    do
    {
        Read_IR();
    } while( (line_data & 0b0100) != 0b0100 );

    return;
}

/*****
 * Turn_Right: Sets motors and delays processor so the
 *             vehicle can get off of the current line and
 *             begin polling for the next line.
 *****/
void Turn_Right(void)
{
    direction--;
    if( direction < 0)
    {
        direction = 3;
    }

    Motors(MF_FORWARD, MF_FORWARD); // Move forward before turning to center rear wheels on the line
    Delay10KTCYx(TURN_TIME);

    Motors(M_FORWARD, M_REVERSE);
    Delay10KTCYx(175);

    do

```

```

    {
        Read_IR();
    } while( (line_data & 0b0010) != 0b0010 );

    return;
}

/*****
 * Turn_Around: Sets motors and delays processor so the
 *              vehicle can get off of the current line and
 *              begin polling for the next line. Do to the
 *              operating environment, special considerations
 *              where taken into the direction of the turn.
 *****/
void Turn_Around(void)
{
    direction ++;
    if( direction > 3)
    {
        direction = 0;
    }
    direction ++;
    if( direction > 3)
    {
        direction = 0;
    }

    if( (x_cur == 0) || (direction == 2) )
    {
        Motors(M_REVERSE, M_FORWARD);

        Delay10KTCYx(0);
        Delay10KTCYx(0);

        do
        {
            Read_IR();
        } while( (line_data & 0b0010) != 0b0010 );
    }
    else
    {
        Motors(M_FORWARD, M_REVERSE);

        Delay10KTCYx(0);
        Delay10KTCYx(0);

        do
        {
            Read_IR();
        } while( (line_data & 0b0100) != 0b0100 );
    }

    return;
}

/*****
 * Back_Up: Reverses the motors and delays for a set
 *          amount of time. No consideration for line
 *          tracking is needed. Polls rear bumper to
 *          determine if a collision has occurred.
 *****/
void Back_Up(void)
{
    unsigned char temp, i;

    Motors(S_REVERSE, S_REVERSE);

    for( temp = 0; temp < 26; temp++ )           // Delay 1.25 seconds
    {
        if( rear_bump == 0 )                       // Object sensed by rear bumper (Active Low)
        {
            Motors(0, 0);

            sprintf(message, "Rear Collision Sensed");
            UPDATE_LCD;

            for( i = 0; i < 13; i++ )             // Delay 6 seconds
            {
                Delay10KTCYx(0);
            }
        }
    }
}

```

```

        }
        Motors(M_REVERSE, M_REVERSE);
    }
    Delay1KTCYx(0);
}
Motors(0,0);
return;
}
/*****
* Navigate: Use value from line following sensors to
* determine what action to take. Stops robot if
* something is in its forward collision path.
* External variables: prev_line_data
* Makes changes to: prev_line_data
*****/
void Navigate(void)
{
    while(1)
    {
        Read_IR();

        if( line_data == 0b0000 )           // No Line
        {
            if( prev_line_data == 0b0100 )
            {
                Motors(S_REVERSE, S_FORWARD);
            }
            else if( prev_line_data == 0b0010 )
            {
                Motors(S_FORWARD, S_REVERSE);
            }
            else
            {
                Motors(0,0);
            }
        }
        else if( line_data == 0b0010 )     // Line to right
        {
            Motors(MF_FORWARD, M_FORWARD);
            prev_line_data = line_data;
        }
        else if( line_data == 0b0100 )     // Line to left
        {
            Motors(M_FORWARD, MF_FORWARD);
            prev_line_data = line_data;
        }
        else if( line_data == 0b0110 )     // Centered on line
        {
            Motors(MF_FORWARD, MF_FORWARD);
        }
        else if( (line_data & 0b1000) == 0b1000 || (line_data & 0b0001) == 0b0001 )
        // Intersection or stop marker
        {
            if( direction == 3 )           // Heading North (facing shelves)
            {
                Motors(0,0);
                return;
            }
            else
            {
                Map_Intersection();
            }
        }
    }
}
return;
}

```

```

/*****
 * Map_intersection: Determines which path to take when
 * arriving at an intersection.
 * External variables: direction, x_cur, x_dest
 * Makes changes to: x_cur
 *****/
unsigned char Map_Intersection(void)
{
    if( direction == 0 ) // Heading East
    {
        x_cur++; // Increment Lane Number

        if( x_cur < x_dest ) //
        {
            Motors(MF_FORWARD, MF_FORWARD);
            Delay10KTCYx(175); // Go Forward & wait before reading next
line data
        }
        else if( x_cur > x_dest )
        {
            Turn_Around(); // Turn Around
        }
        else
        {
            Turn_Right();
        }
    }
    else if( direction == 2 ) // direction == 2 // Heading West
    {
        x_cur--; // Decrement Lane Number

        if( x_cur > x_dest ) //
        {
            Motors(MF_FORWARD, MF_FORWARD);
            Delay10KTCYx(175); // Go Forward & wait before reading
next line data
        }
        else if( x_cur < x_dest )
        {
            Turn_Around(); // Turn Around
        }
        else
        {
            // Arrived at destination
            Turn_Left();
        }
    }
    else // direction == 1 // Heading towards center line
    {
        if( x_cur < x_dest )
        {
            Turn_Right();
        }
        else if( x_cur > x_dest )
        {
            Turn_Left();
        }
    }
}
return;
}

```

```

/*****
 * RF LINK
 *
 * Written for the PIC18F8720 @ 20 MHz (5MHz Instruction)
 * Interfaces: Digital I/O on RHO, RH1, RH2, RH3,
 * and INT1, that connect to a TRF-24G RF module
 * Copyright (2005) Albert Chung
 *
 * NOTES:
 * Hardware Connections:
 *   RHO (I/O):   TRF-24G Data
 *   H1 (Output): TRF-24G CLK1
 *   H2 (Output): TRF-24G CS
 *   H3 (Output): TRF-24G CE
 *   NT1 (I/O):  TRF-24G DR1
 *****/

#include <p18f8720.h>
#include <delays.h>
#include <stdio.h>
#include "interrupts.h"
#include "rf.h"
#include "asrs.h"
#include "bios.h"

unsigned char tx_buffer = 0;
unsigned char rx_buffer = 0;
unsigned char rx_buffer_synch = 0;

unsigned char tx_frame_num = 0b10000000;
unsigned char rx_frame_num = 0b00000000;
unsigned char synch_ctr = 0;

#define ACK 0xAA // Acknowledgement for stop and wait protocol (not used yet)
#define NCK 0xFF // Reject for stop and wait protocol

/*****
 * Tx_EN: Toggles the RF CLK pin.
 *****/

void CLK (void)
{
    Delay10TCYx(10); // 500 nsec (tsetup)
    CLK1 = 1; // clock in the value
    Delay10TCYx(10); // 500 nsec (thold)
    CLK1 = 0;

    return;
}

/*****
 * Tx_EN: Configures the RF module to the transmit
 * mode.
 *****/

void Tx_En(void) // Set module to active transmit mode
{
    signed char i;
    char Tx_2500MHz = (rf_ch << 1);

    DDRHbits.RHO = 0;
    DDRHbits.RH1 = 0;
    DDRHbits.RH2 = 0;
    DDRHbits.RH3 = 0;

    CE = 0; // Set configuration mode
    CS = 1; // Select configuration register

    Delay10TCYx(40); // 10 usec (tcs2data)

    for ( i = 7; i >= 0; i--)
    {
        DATA = Tx_2500MHz >> i; // Shift out RF channel and set to RX_EN = 0
    }
}

```

```

        CLK(); // Clock in the data
    }
    CS = 0; // shift the configuration word into the module
    RF_IRQ_OFF; // Disallow RD1 to interrupt MCU
    Delay10TCYx(100); // 250 usec (tsettling)
    CE = 1; // Turn on ACTIVE TX Mode
    Delay10TCYx(40); // 10 usec (tce2data)
    return;
}

/*****
* Rx_EN: Configures the RF module to the actively
* monitor for incoming packets.
*****/

void Rx_En(void) // Set module to active receive mode
{
    signed char i;
    char Rx_2500MHz = (rf_ch << 1) | 1; // Last byte in configuration word

    DDRHbits.RH0 = 0; // Set Outputs
    DDRHbits.RH1 = 0;
    DDRHbits.RH2 = 0;
    DDRHbits.RH3 = 0;

    CE = 0; // Set configuration mode
    CS = 1; // Select configuration register

    Delay10TCYx(40); // 10 usec (tcs2data)

    for (i = 7; i >= 0; i--)
    {
        DATA = Rx_2500MHz >> i; // Shift out RF channel and set to RX_EN = 1
        CLK(); // Clock in the data
    }

    CS = 0; // shift the configuration word into the module
    DDRHbits.RH0 = 1; // Set Data as Input
    Delay10TCYx(100); // 250 usec (tsettling)
    RF_IRQ_ON; // Allow RD1 to interrupt MCU
    CE = 1; // Turn on ACTIVE TX Mode
    Delay10TCYx(40); // 10 usec (tce2data)

    return;
}

/*****
* Transmit: Adds header error control and clocks out
* data to the RF chip.
*****/

void Transmit (int tx_payload)
{
    int parity;
    signed char i;

    tx_payload = tx_payload << 1;
    tx_payload &= 0b00011110;
    tx_payload |= 0b10100000;

    parity = tx_payload % 2;

    if (parity == 0) // Even
    {
        tx_payload |= 0b00000001;
    }

    Tx_En();
}

```

```

    for ( i = 7; i >= 0; i--)
    {
        DATA = rx_addr >> i;           // Shift out Rx address (MSB first)
        CLK();                           // Clock in the data
    }

    for ( i = 7 ; i >= 0; i--)
    {
        DATA = tx_payload >> i;       // Shift out payload (MSB first)
        CLK();                           // Clock in the data
    }

    CE = 0;                               // Activate Shockburst Tx

    Rx_En();

    return;
}

/*****
* Receive: Clock in data from the RF chip and
* header error control such as parity to determine if
* data is valid.
*****/

void Receive (void)
{
    signed char i;
    int temp_payload = 0;
    int temp;
    int parity;

    for ( i = 7; i >= 0; i--)
    {
        CLK1 = 1;                         // Clock in the data
        Delay10TCYx(10);                  // 500 nsec (tsetup)
        temp_payload |= DATA << i;      // Shift in payload (MSB first)
        CLK1 = 0;
        Delay10TCYx(10);                  // 500 nsec (tsetup)
    }

    parity = temp_payload % 2;
    if (parity == 0)                       // Even
    {
        sprintf(message, "Parity Error %d", temp_payload);
        UPDATE_LCD;
        return;                             // Bad data
    }

    if( ( temp_payload & 0b11100000 ) == 0b10100000 )           // Check the header
    {
        temp_payload = temp_payload >> 1;
        temp = temp_payload & 0b00000111;

        if( temp <= 4 )
        {
            //ASRS COMMAND
            if( ( temp_payload & 0b00001000 ) == 0b00001000 ) // Incoming command
            {
                Queue_Push(temp_payload);           // Place into queue
            }
            else
            // Outgoing command, AGV has removed pallet
            {
                shelves[temp] = 0;                 // Clear location
            }
            // End ASRS COMMAND
        }
    }

    return;
}

```

```

/*****
* Init_RF: Configure the RF module.
*****/

void Init_RF (void)
{
// Set up the configuration packet in segments of 8 bits
// {data_w, addr2 not used = 5x"0", redundant address bits exceeding address width = 3x"0", asrs_addr,
addr_w[bit7:2] crc[bit1:0], mode, rf_ch & receive mode}

char addr_w_crc = ( addr_w << 2 )| crc;
char config[15] = {0,data_w, 0, 0, 0, 0, 0, 0, 0, 0, 0, tx_addr, addr_w_crc, mode, (rf_ch << 1)};
unsigned char i;
signed char j;

DDRHbits.RH0 = 0;
DDRHbits.RH1 = 0;
DDRHbits.RH2 = 0;
DDRHbits.RH3 = 0;

Delay10KTCYx(10); // 5 msec (tpd2sby)

CE = 0; // Set configuration mode
CS = 1; // Select configuration register

Delay10TCYx(40); // 10 usec (tcs2data)

for ( i = 0; i < 15; i++)
{
for ( j = 7; j >= 0; j--) // send the configuration word MSB first
{
DATA = config[i] >> j; // shift config word 1 bit at a time
CLK(); // Clock in the data
}
}

CS = 0; // Shift the configuration word into the module
Rx_En(); // Set the module to active Rx mode

INTCONbits.TMR0IF = 0; // Clear the TMR0 overflow Flag

return;
}

```

```

/*****
* AUTOMATED STORAGE & RETRI EVAL SYSTEM
* Behavioral Routines: Storing, Inventory, Queuing
* EEL5666 Intelligent Machines Design Laboratory
* University of Florida
* Written for the PIC18F8720 @ 20 MHz
* Copyright (2005) Albert Chung 2.12.2005
*****/

```

```

#define QUEUE_LENGTH 8

```

```

extern unsigned char shelves[];
extern unsigned char shelf_num;
extern unsigned char tier_height;
extern unsigned char l0;
extern unsigned char last_fork_height;
extern signed char first;
extern signed char last;
extern unsigned char Queue[];

```

```

// Function declarations
extern unsigned char Queue_Pull(void);
extern void Queue_Push(unsigned char);
extern void Get_Destination(unsigned char);
extern unsigned char Get_Out_Location(void);
extern unsigned char Get_In_Location(void);
extern unsigned char Get_Dock_Location(void);
extern unsigned char Queue_Pull(void);
extern void Move_Pallet(void);
extern void Initialize_Fork(void);
extern void Center_Fork_To_Pallet(void);
extern void Raise_Fork(void);

```

```

/*****
 * ANALOG TO DIGITAL CONVERSION
 *
 * Written for the PIC18F8720 @ 20 MHz
 * Interfaces: Analog inputs on AN0:5
 * Copyright 2005 Trevor Skipp
 *****/

#define ADCH0          Read_AD0()
#define RIGHT_DIST    Read_AD1()
#define LEFT_DIST     Read_AD2()
#define ADCH3         Read_AD3()
#define LEFT_IR       Read_AD4()
#define MID_LEFT_IR   Read_AD5()
#define MID_RIGHT_IR  Read_AD6()
#define RIGHT_IR      Read_AD7()

extern int Read_AD0(void);
extern int Read_AD1(void);
extern int Read_AD2(void);
extern int Read_AD3(void);
extern int Read_AD4(void);
extern int Read_AD5(void);
extern int Read_AD6(void);
extern int Read_AD7(void);

// Line Following declarations
extern int black_l, black_ml, black_mr, black_r;
extern int line_data;
extern int prev_line_data;

```

```
/******  
 * HITACHI LCD CONTROLLER *  
 * * * * *  
 * Written for the PIC18F8720 @ 20 MHz *  
 * Interfaces: Enable on RDO, RS on RD1, DB4:7 on *  
 * RD4:7 *  
 * Copyright 2005 Albert Chung & Trevor Skipp *  
*****/  
  
#define INIT_LCD LCD_Init();  
#define UPDATE_LCD Update_LCD();  
  
extern char message[];  
  
extern void LCD_Init(void);  
extern void Update_LCD(void);
```

```

/*****
 * Interrupt Polling
 *
 * Written for the PIC18F8720
 * Written by Albert Chung & Trevor Skipp
 *****/

```

```

#define GLOBAL_IRQ_ON  Init_Global_IRQ()
#define INIT_CCP_IRQ  Init_Capture_IRQ()
#define RF_IRQ_ON     Init_RF_IRQ()
#define RF_IRQ_OFF    Disable_RF_IRQ()
#define TMR0_IRQ_ON  Init_TMR0_IRQ()
#define TMR0_IRQ_OFF Disable_TMR0_IRQ()

```

```

extern void Init_Global_IRQ(void);
extern void Disable_Global_IRQ(void);
extern void Init_RF_IRQ(void);
extern void Disable_RF_IRQ(void);
extern void Init_TMR0_IRQ(void);
extern void Disable_TMR0_IRQ(void);
extern void Init_IR_IRQ(void);
extern void Init_TMR3_Overflow_IRQ(void);
extern void Init_Fork_Limit_IRQ(void);

```

```

extern unsigned char timeout_ctr;

```

```

/*****
 * MOTOR CONTROLLER
 *
 * Written for the PIC18F8720 @ 20 MHz
 * Interfaces: Digital outputs on CCP1, 3, 4, 5 that
 * connect to a JRC Dual H-Bridge NJM2670.
 * Copyright (2005) Trevor Skipp
 *****/

#define MF_FORWARD 155
#define M_FORWARD 125
#define S_FORWARD 105
#define S_REVERSE -105
#define M_REVERSE -125
#define MF_REVERSE -155

#define UP 1
#define DOWN -1
#define STOP 0

extern int left_old_speed;
extern int left_new_speed;

extern int right_old_speed;
extern int right_new_speed;
extern unsigned char fork_direction;

extern void PWM_Init(void);
extern void Fork(signed char direction);
extern void Motors(int left_desired_speed, int right_desired_speed);

```

```
/******  
 * LINE FOLLOWING *  
 * * *  
 * Written for the PIC18F8720 @ 20 MHz *  
 * Interfaces: Digital I/O on RH0, RH1, RH2, RH3, *  
 * and INT1, that connect to a TRF-24G RF module *  
 * Credit: William Dubel original code *  
 * *  
*****/
```

```
extern signed char direction;  
extern unsigned char x_cur;  
extern unsigned char x_dest;
```

```
extern void Calibrate_LF(void);  
extern void Turn_Left(void);  
extern void Turn_Right(void);  
extern void Turn_Around(void);  
extern void Back_Up(void);  
extern void Navigate(void);
```

```
extern unsigned char Read_IR(void);
```

```

/*****
 * RF LINK
 *
 * Written for the PIC18F8720 @ 20 MHz
 * Copyright (2005) Albert Chung
 *****/

#define DATA PORTHbits.RH0
#define CLK1 PORTHbits.RH1
#define CS PORTHbits.RH2
#define CE PORTHbits.RH3

#define rx_addr 0b11011101
#define tx_addr 0b11100110
#define data_w 8
#define addr_w 8
#define crc 0b11 // CRC enable
#define mode 0b01001111 // Rx2En = 0, Shockburst Mode, 250kbps, 16 MHz module crystal, 0db Power
#define rf_ch 0x64 // 2500 MHz frequency channel
#define header 0b01010000

extern unsigned char tx_buffer;
extern unsigned char rx_buffer;

extern void Transmit(int tx_payload);
extern void Receive(void);
extern void Init_RF(void);
extern unsigned char Frame(unsigned char job_type, unsigned char dock_num);

```