Innovation First, Inc.

2004 Programming Reference Guide

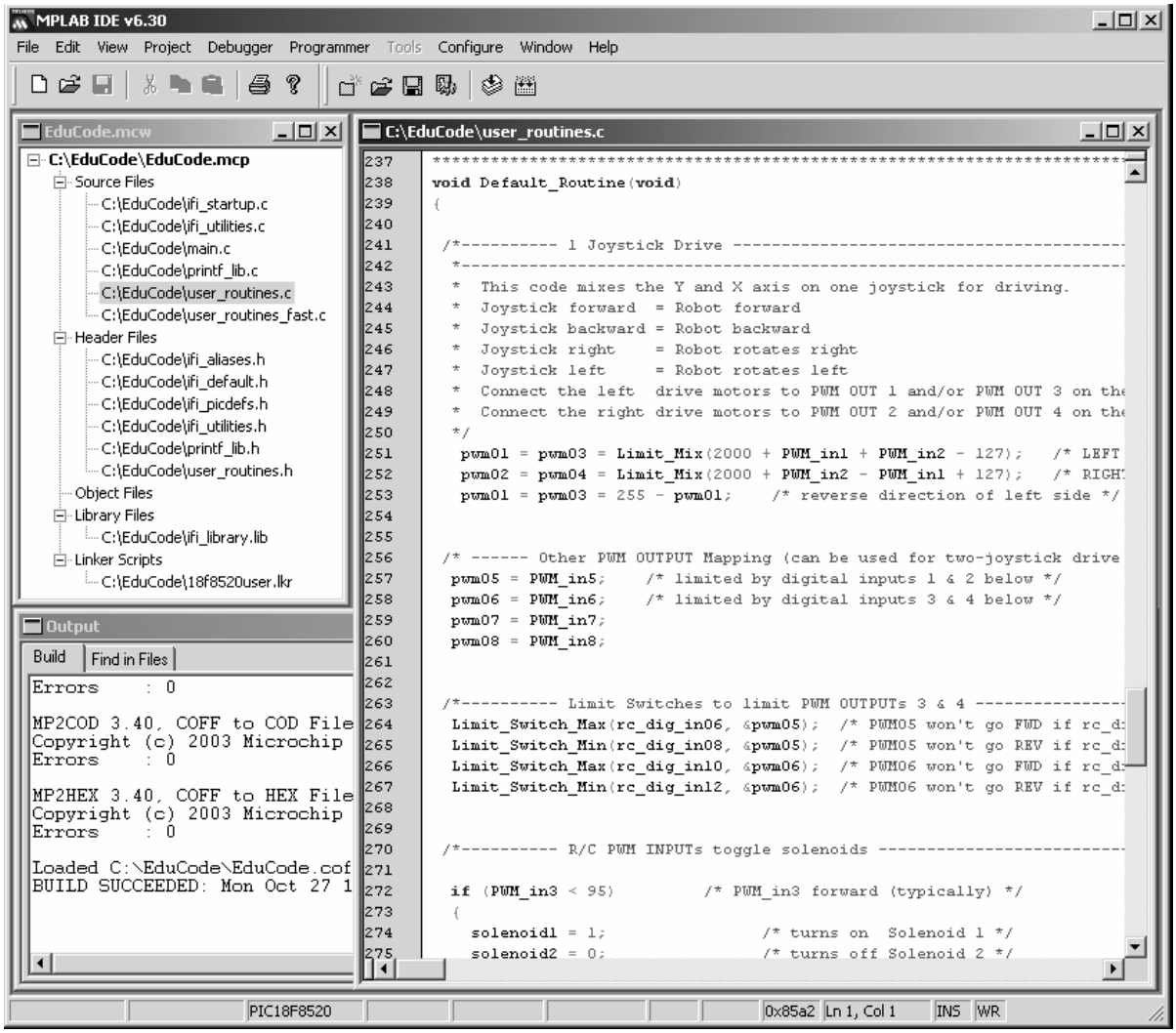
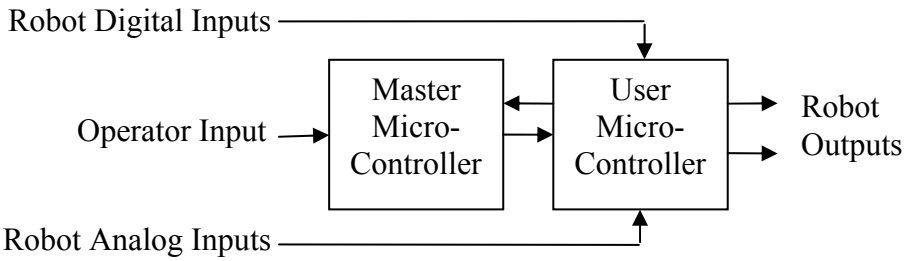


Table of Contents

1. PICmicro Processor and Memory

1.1. Processors

Each Robot Controller has two built-in PICmicro 18F8520 microcontrollers from Microchip Technology. One of these PICmicros uses memory that is programmable by the user. This programmability allows customization of user controls, semi-automatic robot functions, and autonomous robot functions. This User processor has access to all operator input data and robot sensor data, as well as control over the PWM and digital outputs used to control motors, relays, solenoids, etc.



1.2. PICmicro MCU Program Memory

The PICmicro in each Robot Controller has onboard FLASH memory that can be used to store the user's custom programs. This memory is non-volatile; meaning that it keeps its memory after power has been removed. There is a total of 32k bytes of memory space available to the user in which to store custom programs.

The program in the Robot Controller can be changed by downloading a new program into the PICmicro memory through the PROGRAM port (more details in Section 5 on page 22).

1.3. Default vs. Custom Programs

The Robot Controller is supplied with a "Default" program loaded into memory in order to help get the robot up and running quickly. When more sophisticated control of the robot is desired, a custom program can be quickly created by modifying the Default program. Default "Source Code" for the default programs are provided at www.InnovationFirst.com. Since Innovation First offers both a smaller EDU Robot Controller and a full-size Robot Controller, two different sets of code are provided on the web site. The programs are not interchangeable from one type to the other, but the manner of programming is the same.

1.4. Programming Language and Windows Software

Programs for the Robot Controller can be written in Assembly language or C. For ease of use, the default code has been written in the C programming language. This high-level language was selected because it is very powerful and has become an industry standard. Should the user desire, Assembly code can also be mixed with the C code.

Throughout this document it is assumed that the reader is familiar with the C programming language and its conventions.

MPLAB IDE is the name of the free Windows program used to edit, compile, and debug PICmicro programs. *MPLAB C18* is the name of the C compiler that must also be installed for use with *MPLAB IDE*. Microchip has developed a special version of this C compiler for use with Innovation First Robot Controllers. This product, called C-BOT, is included in some Robot Controller kits, or it may be purchased separately from Innovation First. If you have the full version of *MPLAB C18*, it will also work.

For downloading custom programs to the Robot Controller, a program named *IFI Loader* must be used. This is included in the C-BOT package, or you can get this program and the Default Code for your Robot Controller as free downloads from www.InnovationFirst.com.

2. PICmicro Software Structure

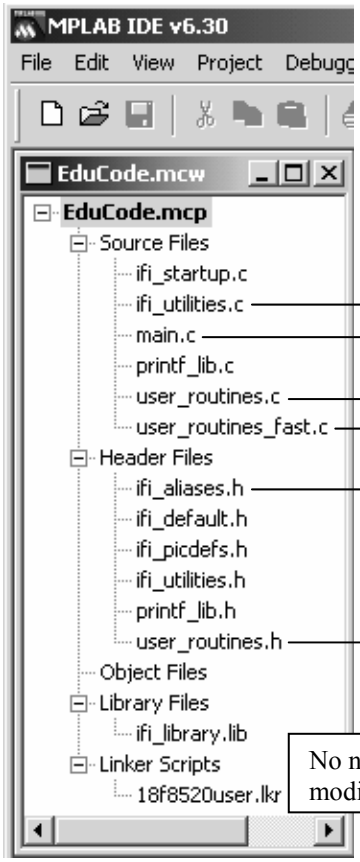
Inside *MPLAB IDE* is where the Robot Controller's program is edited and compiled. From the "File/Open Workspace…" menu you should open the workspace (`.mcw`) file downloaded from the Innovation First web site. You will then see a window listing all the files used in the project (`.mcp`). All of these files are necessary, but only a few of them should be edited by the user to create a custom program. See the next page for details on which files should be edited. To open a file for viewing or editing, double click on it in the workspace window.

The PICmicro program used in the Innovation First Robot Controllers must adhere to a pre-defined structure. The structure does not limit the capability of your software; the structure ensures that the Robot Controller operates properly. This structure is described in the block diagram on the next page.

You can refer to Microchip's MPLAB C18 C Compiler Libraries manual for more information on PICmicro commands. That document will not teach you to program in C, but it details libraries specific to the PICmicro architecture. Not all of the libraries can be used to program the Robot Controller, as specific functions and registers are reserved for correct operation in the Robot Controller system.

For Assembly language instructions and detailed PICmicro device information, refer to the 18FXX20 datasheet from Microchip.

Note that there is a 64 character path/name limit inherent in the Microchip compiler. This means that you will get a compilation error if you try to compile a project which has any file whose path and name length exceeds 64 characters. Therefore your working project directory should be at or near the root of the file-system. (e.g. C:\EduCode\ )



The user must only edit these three files:
`user_routines.c`
`user_routines_fast.c`
`user_routines.h`

Useful functions reside in here.

Advanced users can add to this file.

Refer to this file for useful aliases.

User may add macros and function prototypes here.

No need to modify this file.

Primarily edit this file.

`main.c`

IFI Initialization

User Initialization

Call User Code

`user_routines.c`

Initialize Variables
Set up Inputs/Outputs

Getdata
Data Input

Map user inputs to outputs

Process local sensor inputs

Prepare feedback for OI
(full-size RC only)

Putdata
Data Output

Main Loop

2.1. Comment Format

Comments are additional text added to a program to clarify what the code is doing, or to explain concepts important to understanding the code in the larger context of the robot. Comments are ignored by the compiler and are not processed by the microcontroller. Lines are commented by enclosing the comment text within the following structure: `/* */`

Comment Line Examples: The line of code below is completely commented (line starts with `/*` and ends with `*/`) and is used for informational purposes. It has no effect on the operation of a program.

```
/* This text is for informational purposes and is not processed by the compiler. */
```

Comments can span more than one line:

```
/* Beginning of comment
   Continuing comment
   End of comment
*/
```

You cannot nest comment structures. The following is illegal and will not compile:

```
/* This is /* not allowed */ and won't work. */
```

2.2. Declare Variables

All variables used in the programs must be declared by type and name . The 18F8520 has 2k bytes of data memory available in which to store variables. Variables may be declared in the `.c` file where they are used. There are two primary types of variables that are used in the default Robot Controller code. For variables whose values might range from 0 to 255, the type of `unsigned char` is used. When values might range from 0 to 65535, `unsigned int` is used. See MPLAB C18 C Compiler User's Guide (Section 2.1 on page 9) for details on all data types supported by the 18F8520.

Note that floating point support is implemented using a software library, which makes floating point math significantly slower than integer math. This could impact the operation of your robot if your code takes too long to execute, so be careful.

The default code defines all the standard input and output variables. The names of the variables used in the default program can be changed; however, use caution since the name is used throughout the default code and must be changed at every instance. Declare any additional variables required. The best practice is to affix all your new variables with the same prefix in order to avoid using the same names as elsewhere in the default code. This also enables you to easily share code with other users without worrying about clashes of global variables that have the same name. The examples below use the author's initials as a prefix.

Declare Variables Examples:

```
/* This is how variables are declared. */
unsigned char    dm_loop_count;
unsigned int     dm_output_value;      /* Don't forget the semicolon! */

/* You can declare more than one variable of the same type per line. */
unsigned char    dm_loop_count1, dm_loop_count2, dm_loop_count3;

/* You can also initialize the value of variables at the same time you declare them. */
unsigned int     dm_countdown = 10;
float            dm_pi = 3.1415;
```

Sharing Variables Between Files Example: If you want to use the same variable (and its value) in more than one file, this is how you would do it. This is commonly referred to as a global variable.

```
unsigned int dm_wheel_turns = 25;   /* Declared in user_routines.c, for example. */
```

If a variable is defined in user_routines.c (as in the first line above), but you also want to use this variable in user_routines_fast.c, you must put the following line at the top of user_routines_fast.c.

```
extern unsigned int dm_wheel_turns; /* Put at the top of user_routines_fast.c, for example.*/
```

2.3. Define Macros Used as Aliases

Macros provide alternate and sometimes shorter names for constants, variables, and sub-divisions of variables. In the old IFI control systems using PBASIC, alternate names for system variables were called aliases. In the new system this is achieved by using macros. Macros are substituted into your code at compile-time, and simply make your code easier to write and read. They also don't use any additional program memory, so you can use them liberally.

Just like in the old system, aliases are used to provide logical names for the Analog Inputs, Digital I/O, Relay Outputs, Solenoid Outputs, and PWM Outputs. Macro aliases can also be used to point to a specific bit within a byte, as in the example below. In the default code, all macro aliases have been placed in the `ifi_aliases.h` file. You may add your own macros to the `user_routines.h` file.

Define Aliases Example: Each line declares one alias. After each variable you can place comments on the use of the alias in your application. You can see how aliases can save you a lot of typing.

```
#define dm_countup     dm_countdown   /* countdown and countup refer to the same variable. */
#define rc_dig_int01   PORTBbits.RB2  /* Refers to a specific input pin of the PICmicro. */
#define limit_switch1  rc_dig_int01   /* Multiple aliases for the same item are allowed. */
#define p1_sw_trig     rxdata.oi_swA_byte.bitselect.bit0     /*Joystick Trigger Button */
```

2.4. Define Macros Used as Constants

Macros can also be used to define constants, which are names with fixed values assigned to them. Constants provide a convenient means to organize, locate, and edit these values in your code. They do not require any program memory or code space, and it is very good programming practice to use them instead of typing the numeric value each time. This way it is easy to make changes, and it is also easy to remember what a value represents. It is recommended that you assign your constants at the top of the `user_routines.h` file.

Define Constants Example: Each line below assigns one constant. The Default Code has several examples of constants.

```
#define   DATA_SIZE          30
#define   SPI_TRAILER_SIZE   2
#define   SPI_XFER_SIZE      DATA_SIZE + SPI_TRAILER_SIZE   /* So it will equal 32. */
#define   PWM_NEUTRAL        0x7F       /* This is how to write the hexadecimal number 7F. */
```

2.5. Initialization

Every C program has a function called `main`. This is, exactly as it sounds, the primary routine of the program, and is located inside the `main.c` file. The first thing that is done inside the main function is to initialize the program, or set things up for the first time.

First a routine called `IFI_Initialization()` is called, which sets up crucial system parameters. This call should not be deleted or tampered with.

Next the routine called `User_Initialization()` is called. This function resides in the `user_routines.c` file and may be edited by the user. In this routine the multi-function pins of the Robot Controller can be set up as either digital inputs or digital outputs (or analog inputs for the EDU Robot Controller). Follow the examples given in the code to accomplish this.

Not all pins, registers, functions, and peripherals of the 18F8520 User processor are available to the user. In the initialization section, as throughout your custom code, be careful not to address, use, or otherwise modify any of them which are already in use elsewhere in the default code. For a list of features which are off-limits or unusable, please look in the `ifi_picdefs.h` file. Ports and registers which should not be used are marked with the comment: `/* Reserved - Do not use */`

For the most part you should not run into any problems using reserved ports or registers, unless you are trying to use some very advanced features, so don't panic. You can't break anything by trying, either, so don't be afraid to experiment. The 18F8520 is a very powerful chip, so try to use its full potential.

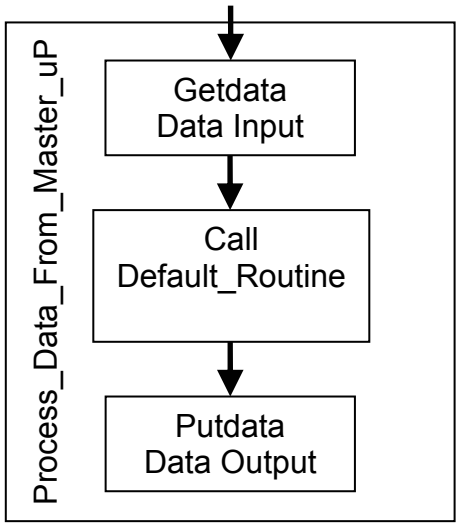
2.6. main.c: while(1)

This is where the Main Loop begins. Since we want our program to continuously execute, rather than only run one time and stop, there is a `while` loop inside `main`. Essentially it is saying "While 1 is true, execute everything between my { } braces." Since 1 is always true, this will loop forever.

2.7. user_routines.c: Process_Data_From_Master_uP();

The core function of the default PICmicro program is to call the `Process_Data_From_Master_uP()` function. This routine performs the following:

1. Read in the Input Data from the operator and on-board robot sensors.
2. Perform specific functions based on the Input Data.
3. Send out the results to perform physical movement of the robot's motors, valves, etc.



This structure ensures that 1) new inputs (joysticks, etc.) are continuously read in, and 2) the outputs (motors, Victors, Spikes, Solenoids, etc.) continuously receive new commands.

As you can see in `main.c`, the `Process_Data_From_Master_uP()` function is only called every 17ms for the EDU Robot Controller and every 26ms for the FRC Robot Controller. This is because the Master processor only sends fresh data to the User processor at that rate.

While this is the maximum rate at which new data is received from the remote operator, it is possible to execute faster code by placing it outside the fixed timing loop, inside the `Process_Data_From_Local_IO()` routine in the `user_routines_fast.c` file. Anything in this function will execute at the fastest rate possible, or every time the main loop repeats. Before using it, though, you should make sure you understand and can use the slower `Process_Data_From_Master_uP()` loop, so we will continue our explanation…

2.8. user_routines.c - Getdata Data Input

The first part of the Main Loop is the `Getdata` command. This command reads a serial stream of data from the Master processor. For proper operation of the Robot Controller this command should not be moved or modified. `Getdata` is very similar to the old SERIN command from the older PBASIC systems.

2.9. user_routines.c – Default_Routine call: Perform Operations Here

After the `Getdata` function is called and new data is received, the `Default_Routine()` routine is called. This routine is also located in `user_routines.c` and this is where all the default operation of the robot is assigned. You can modify this routine to re-map the inputs to outputs, and to perform special functions. If you do not wish to execute any of the code in the Default_Routine, you can delete that line or comment it out.

Perform Operations Example: The main loop below is an abridged example of the FRC Default_Routine. Refer to the Default Code for a more complete example. The code below performs the following functions:

1. Port 1 Y axis linked to PWM1. PWM2 and PWM3 are set to neutral.
2. Port 3 Trigger activates Relay 3 in the Forward direction. See the Relay Outputs on page 20.
3. Port 3 Thumb button activates Relay 3 in the Reverse direction.
4. Robot digital input 1 automatically activates the roller forward at the speed set by constant ROLLER_SPEED.

```
/*========= PERFORM OPERATIONS ================================================================*/

/*--------- Joystick to PWM ------------------------------------------------------------------*/
  pwm01 = p1_y;
  pwm02 = 127;              /* Set to neutral. */
  pwm03 = PWM_NEUTRAL;      /* Another way to set to neutral.  Remember our constant? */

/*--------- Button to Relay ------------------------------------------------------------------*/
  relay3_fwd = p3_sw_trig;  /* Relay 3 Forward = Port 3 Trigger */
  relay3_rev = p3_sw_top;   /* Relay 3 Reverse = Port 3 Thumb button */

                            /* relay3_fwd is an Alias to a bit an output pin. */
                            /* p3_sw_trig is an Alias to a bit in oi_swA_byte. */

/*--------- Roller Code ----------------------------------------------------------------------*/
  if (rc_dig_in01 == 0)          /* Don't forget to use a double-equals for conditionals! */
  {
    Roller_Out = ROLLER_SPEED;
  }
  else
  {
    Roller_Out = PWM_NEUTRAL;
  }
```

2.10. user_routines.c – "Add your own code here."

In this section you can add any custom code you wish. You make your own function and call it here, or you can just add your code in-line before the `Putdata` call. You are also welcome to leave it blank.

2.11. user_routines.c - Putdata Data Output

The final part of the Main Loop is the `Putdata` command. This command sends a serial stream of data back to the Master processor. The Master processor then uses this data to drive some of the PWM outputs and to monitor the status of the User processor. `Putdata` performs a function very similar to the SEROUT command from the older PBASIC systems.

Do not delete, modify, or move the `Putdata` command line. If it is not executed at least every 17 ms (for the EDU system) or 26.2ms (for the FRC system), the Master processor will disable the User processor and your RC will not function. You can tell this has happened if the PROGRAM STATE LED is flashing red. For this reason you should not put any infinite loops in your code, or any other code which might take a very long time to execute. Remember, extensive use of floating point math can take a very long time, so be careful.

On the other hand, calling the Putdata function more frequently than this rate is not particularly advantageous, although neither is it harmful. It will not make the Master processor do anything more often with the data sent to it. Therefore, inside the `Process_Data_From_Master_uP()` function is the best place for it.

It is recommended that you set unused PWM outputs to 127, unused relay and digital outputs to 0, and unused solenoid outputs to 0 before calling the `Putdata` function.

On the FRC, the Master processor will disable all outputs if there is no communication with the Operator Interface or if the Competition Mode is Disabled, unless you set the Robot Controller to run in Autonomous mode. See the appropriate user's manuals for details on these conditions.

Also, in the FRC system the Master processor sends the data received from the `Putdata` command over the radio link back to the Operator Interface, so that the user can have some form of feedback, whether by LEDs, on the multi-segment display, or on their PC using the Dashboard software (available from www.InnovationFirst.com).

2.12. user_routines.c – Return to main.c

The Main Loop is now complete. Program execution will return to the top of the `while(1)` loop in the `main.c` file and do it all again. This loop will repeat forever.

3. Program Inputs

The following sections describe the types of data input to the PICmicro program. The User program receives the remote operator's input data from the Master processor inside the Robot Controller. Most inputs, however, come from local sensors and ports on the Robot Controller which are connected directly to the User processor.

Remote Operator Inputs

For a FIRST Robotics Control System which uses an RS-422 Radio for communicating with an Operator Interface, the human operator's controls (both digital and analog) are passed into the Robot Controller through the radio port. The Master processor handles this communication and then sends the control signals to the User processor.

For an EDU Robot Controller the human operator's commands are sent using a standard hobby radio-control (R/C) transmitter and receiver pair. The hobby R/C receiver is interfaced with the Robot Controller as detailed in the Robot Controller's user guide. The Master processor takes the signals from the hobby R/C receiver and digitizes them before sending them to the User processor.

Local Sensor Inputs

The other inputs to the User program come from the pins on the Robot Controller which are connected directly to the User processor. The User program has access to these pins and can get both digital and analog information from them.

The next two sections will talk about the digital and analog inputs that are received by the User processor inside the Robot Controller, whether from the remote operator or from local sensors.

3.1. Digital Inputs

Digital Inputs are defined as inputs that are either HIGH or LOW. Buttons and switches are the most common form of digital inputs. In software a digital input is either a zero (0 = LOW) or a one (1 = HIGH). The Digital Inputs on the Robot Controllers and Operator Interfaces have pull-ups, which means that they are normally high, or 1 when not connected to anything. That means that if a digital input is open or not connected, the value read by the PICmicro digital input is HIGH (= 1). If a digital input is connected to ground, the input is LOW (= 0). The buttons on the joysticks are an example of switches connected to digital inputs on the Operator Interface. Limit switches are often connected to digital inputs on the Robot Controller.

Operator Interface Digital Inputs

Only the FRC Robot Controller can communicate with the Operator Interface. Refer to the Operator Interface Reference Manual for details on the Digital Inputs. The sixteen (16) Digital Inputs from the Operator Interface are grouped into two bytes, `OI_SWA` and `OI_SWB`. These input variables are aliased into more meaningful names such as `p1_sw_trig` which refers to the trigger of the Joystick connected to Port 1.

Digital Inputs: The Operator Interface Digital Input aliases are found in the file `ifi_aliases.h` of the Default Code.

```
/*--------- Example aliases for each OI switch input -------------------------------------*/
#define p4_sw_trig  rxdata.oi_swB_byte.bitselect.bit4 /*Joystick Trigger Button*/
#define p4_sw_top   rxdata.oi_swB_byte.bitselect.bit5 /*Joystick Top Button*/
#define p4_sw_aux1  rxdata.oi_swB_byte.bitselect.bit6 /*Aux input*/
#define p4_sw_aux2  rxdata.oi_swB_byte.bitselect.bit7 /*Aux input*/
```

Robot Controller Digital Inputs

Refer to the appropriate Robot Controller Reference Manual for details on the number and location of the Digital I/O pins. They are pins which go directly to the User processor. These pins can be configured as either inputs or outputs in your initialization. See the `User_Initialization` routine in `user_routines.c` for examples of configuring pins as inputs.

The Default Code already has some of these I/O pins set up as Inputs that you can use with no change to the initialization code. They can be referenced using aliases as in the following examples.

Digital Inputs: The Robot Controller Digital Input aliases are found in the `ifi_aliases.h` file.

```
/*--------- Example aliases for default FRC RC digital inputs ----------------------*/
#define rc_dig_in13     PORTGbits.RG4
#define rc_dig_in14     PORTCbits.RC0
#define rc_dig_in15     PORTJbits.RJ4
#define rc_dig_in16     PORTJbits.RJ5

/*--------- Example aliases for default EDU RC digital inputs ----------------------------*/
#define rc_dig_in13     PORTHbits.RH4
#define rc_dig_in14     PORTHbits.RH5
#define rc_dig_in15     PORTHbits.RH6
#define rc_dig_in16     PORTHbits.RH7
```

NOTE: There are differences between the pin-outs of each type of Robot Controller. This is why the full-size and EDU Robot Controllers each have a different version of code and they are not interchangeable.

3.2. Analog Inputs

Analog Inputs are defined as inputs that can have any voltage value between 0 and 5 volts, not just ON or OFF. Joysticks, Potentiometers, and Gyro sensors are typically connected to Analog Inputs. Both the Robot Controller and the Operator Interface (FRC system only) have the capability to measure analog inputs.

Operator Interface Analog Inputs

Refer to the Operator Interface Reference Manual for details on the Analog Inputs. The sixteen (16) Analog Inputs from the Operator Interface are each stored in bytes, such as `p1_x` and `p1_y` corresponding to the X and Y Joystick axis connected to Port 1. The CH FlightStick joystick used with the Operator Interface has three analog inputs per joystick, the X axis, the Y axis, and the Wheel.

In software, an analog input from the Operator Interface (FRC only) is represented as a number from 0 to 254. The table below shows how an Analog Input varies as the joystick is moved. In the FRC Robot Controller's Default Code, the Analog Inputs from the Operator Interface are mapped directly to the PWM Outputs without modification (see PWM Outputs on page 17). The EDU system uses the joysticks on standard hobby radio controllers as remote analog inputs. These inputs are similarly mapped directly to the PWM Outputs on the Robot Controller.

Joystick Function	Position and Analog Input Value		
Y Axis	Full Forward = 254	Neutral = 127	Full Back = 0 – 25*
X Axis	Full Left = 254	Neutral = 127	Full Right = 0 – 25*
Wheel	Full Forward = 254	Neutral = 127	Full Back = 0 – 25*

* Note: The joystick axes rarely go all the way to zero. This is normal. See PWM Outputs on page 17.

Analog Inputs: The Operator Interface Analog Input aliases are found in the file `ifi_aliases.h` of the FRC Default Code.

```
/*--------- Operator Interface (OI) - Analog Inputs -------------------------------------*/
#define p1_y        rxdata.oi_analog01
#define p2_y        rxdata.oi_analog02
#define p3_y        rxdata.oi_analog03
#define p4_y        rxdata.oi_analog04
#define p1_x        rxdata.oi_analog05
#define p2_x        rxdata.oi_analog06
#define p3_x        rxdata.oi_analog07
#define p4_x        rxdata.oi_analog08
#define p1_wheel    rxdata.oi_analog09
#define p2_wheel    rxdata.oi_analog10
#define p3_wheel    rxdata.oi_analog11
#define p4_wheel    rxdata.oi_analog12
```

Radio Control PWM Analog Inputs

Refer to the EDU Robot Controller Reference Guide for details on interfacing it with standard hobby radio control (R/C) transmitters and receivers. The joystick movements from the transmitters then become inputs to the Robot Controller, with their corresponding values stored in bytes.

Analog Inputs: The hobby R/C receiver input aliases are found in the file `ifi_aliases.h` of the EDU Default Code.

```
/*---------- Aliases for each radio-control receiver PWM input ---------------------------*/
#define PWM_in1     rxdata.oi_analog01
#define PWM_in2     rxdata.oi_analog02
#define PWM_in3     rxdata.oi_analog03
#define PWM_in4     rxdata.oi_analog04
```

Robot Controller Analog Inputs

The Robot Controller Analog Inputs have a 10-bit resolution. Refer to the appropriate Robot Controller Reference Guide for details on the number and location of the Analog Inputs. (Note: The Analog Inputs of the EDU Robot Controller are configured in the initialization section, as they can also be used as Digital I/O if desired. The EDU Default Code already has some of these Analog Inputs configured so that you can use them with no change to the initialization code.)

In order to use them you must call the `Get_Analog_Value` function, which resides in the `ifi_utilities.c` file. This function will return a 10-bit value stored in an `unsigned int`, or two bytes. See the example below if you want to map the 10-bit value to an 8-bit variable, like a PWM output.

Analog Inputs: The Robot Controller Analog Inputs are found in the file `ifi_aliases.h` and used as follows.

```
/*--------- Robot Controller (RC) - Analog Input Aliases ----------------------------------*/
#define rc_ana_in01  ADC_CH0
#define rc_ana_in02  ADC_CH1
#define rc_ana_in03  ADC_CH2
#define rc_ana_in04  ADC_CH3

/* Example of using the Analog Inputs to map an analog input to a PWM output. */

unsigned int sensor1;
unsigned char sensor1_8bits;

sensor1 = Get_Analog_Value( rc_ana_in01 );     /* Assign the analog reading to a variable. */
sensor1_8bits = (unsigned char)(sensor1 >> 2); /* Only take the 8 most significant bits,   */
pwm01 = sensor1_8bits;                         /* because PWM OUTPUTS can only be 8 bits.  */

/* Or you can do it all in one line like this. */
pwm01 = (unsigned char) (Get_Analog_Value(rc_ana_in01) >> 2);
```

4. Program Outputs

The following sections describe the types of data and actions that are output from the PICmicro program. Most of the output pins of the Robot Controller are directly tied to the User processor and can be addressed by the user in their code.

4.1. PWM Outputs

The PWM Output Ports on the Robot Controllers are all controlled by PICmicro software. Each PWM output provides variable speed control for a motor in both Forward and Reverse.

PWM stands for Pulse Width Modulation and is the type of signal commonly used to control Speed Controllers such as the Victor 884. This PWM signal is the standard hobby R/C type used on model airplane controls. This PWM is not the regular duty-cycle type output by most microcontrollers.

PWM Outputs: The PWM outputs have aliases defined in the `ifi_aliases.h` file. By assigning a value from 0 – 255 to them you can control the speed of a motor.

```
/*--------- Example Aliases for Robot Controller PWM outputs ------------------------------*/
#define pwm01       txdata.rc_pwm01
#define pwm02       txdata.rc_pwm02
#define pwm03       txdata.rc_pwm03
#define pwm04       txdata.rc_pwm04
```

In the EDU system any given PWM output signal can be created by either the Master or the User processors. See the `Setup_Who_Controls_Pwms` function in the `User_Initialization` routine of the `user_routines.c` file in the EDU Default Code to do this. In the Default Code the Master processor controls all PWMs according to the values stored in `pwm0x` variables and sent in the `PutData()` function. This means that PWM outputs can only be changed every 17ms when the Master gets the new values from the User processor. If the User processor is set up to control one or more PWM outputs, it can change those outputs every program loop if desired by using the `Generate_Pwms` function.

EDU Robot Controller PWM Outputs: Here are some example lines of code to show how the PWMs are controlled.

```
/* Setup Master processor to control PWMs 1-4, User to control PWMs 5-8. */
   Setup_Who_Controls_Pwms(MASTER,MASTER,MASTER,MASTER,USER,USER,USER,USER);

   pwm01 = pwm02 = pwm03 = pwm04 = pwm05 = pwm06 = pwm07 = pwm08 = 42;

/* Every 17ms the Master will generate PWMs 1-4 with the values stored in pwm0x variables. */
   Putdata(&txdata);

/* The User processor will generate PWMs 5-8 with whatever values are passed as arguments to
this function.  Notice that the values for PWMs 1-4 will be ignored, since the Master
controls them.  Also notice that PWM 8 will be set at neutral.  It must be type-cast. */
   Generate_Pwms(1,Z,ZERO,ZERO,pwm05,pwm06,pwm07,(unsigned char)127);
```

In the FRC system the values for PWM signals 1-16 are all sent to the Master processor from the User processor using the `PutData()` function. The Master processor, however, only uses this data to generate the signals for PWMs 1-12. The signals for PWMs 13-16, on the other hand, are generated directly by the User processor by using the `Generate_Pwms` function. This means that PWMs 1-12 can only be changed every 26ms, while 13-16 can be changed as often as the program loop executes if called more frequently. You must use both the `Putdata(&txdata)` and the `Generate_Pwms(pwm13,pwm14,pwm15,pwm16)` commands to generate all 16 PWM output signals.

The most common method of controlling an FRC PWM output is via the joystick Analog Input. By sending a joystick Analog Input to a PWM output, a motor connected to the PWM port will act as follows:

Action (FRC system)	Function and Analog Value		
PWM Speed Controller	Full Forward = 254-227	Neutral = 136-123	Full Reverse = 0 – 37
Joystick Y Axis	Full Forward = 254	Neutral = 127	Full Back = 0 – 25
Joystick X Axis	Full Left = 254	Neutral = 127	Full Right = 0 – 25
Joystick Wheel	Full Forward = 254	Neutral = 127	Full Back = 0 – 25

Refer to the appropriate Robot Controller Reference Manual for details on the number and location of the PWM Outputs.

Example (using the default FRC software): Move the Y-axis on the Port 1 Joystick forward to make a motor connected to PWM1 turn. The further you push the joystick, the faster the motor turns. From a neutral position move the Y-axis on the Port 1 Joystick backwards to make a motor connected to PWM1 turn the other direction. Again, the further you push the joystick, the faster the motor turns.

FRC Robot Controller PWM Outputs: The FRC default code maps the joystick Analog Inputs from the Operator Interface to the PWM outputs as follows. Elsewhere in the code, the Generate_Pwms() and Putdata() functions are called to generate the PWM output signals.

```
/*---------- Analog Inputs (Joysticks) to PWM Outputs-----------------------
 *   This maps the joystick axes to specific PWM outputs. */
  pwm01 = p1_y;
  pwm02 = p2_y;
  pwm03 = p3_y;
  pwm04 = p4_y;
  pwm05 = p1_x;
  pwm06 = p2_x;
  pwm07 = p3_x;
  pwm08 = p4_x;
  pwm09 = pwm13 = p1_wheel;
  pwm10 = pwm14 = p2_wheel;
  pwm11 = pwm15 = p3_wheel;
  pwm12 = pwm16 = p4_wheel;

  Generate_Pwms(pwm13,pwm14,pwm15,pwm16);
  Putdata(&txdata); /* Send my data to the master microprocessor. */
```

NOTE: If you call the `Generate_PWMs` routine too quickly, not every device to which you send the signal may be able to handle the fast update rate. Please check the device specifications or else experiment to determine how often the routine may be called for your application.

4.2. Standard Digital Outputs

Refer to the appropriate Robot Controller Reference Manual for details on the number and location of the Digital I/O pins. They are pins which go directly to the User processor. These pins can be configured as either inputs or outputs in your initialization. See the `User_Initialization` routine in `user_routines.c` for examples of configuring pins as outputs.

The Default Code already has some of these I/O pins set up as Outputs that you can use with no change to the initialization code. They have aliases as in the following examples.

Digital Outputs: The Robot Controller Digital Output aliases are found in the file `ifi_aliases.h` of the Default Code.

```
/*--------- Example aliases for default FRC RC digital outputs ----------------------*/
#define rc_dig_out13    LATGbits.LATG4
#define rc_dig_out14    LATCbits.LATC0
#define rc_dig_out15    LATJbits.LATJ4
#define rc_dig_out16    LATJbits.LATJ5

/*--------- Example aliases for default EDU RC digital outputs ----------------------------*/
#define rc_dig_out13    LATHbits.LATH4
#define rc_dig_out14    LATHbits.LATH5
#define rc_dig_out15    LATHbits.LATH6
#define rc_dig_out16    LATHbits.LATH7

/*--------- Example usage of digital outputs ----------------------------------------------*/
  if (pwm01 > 227)             /* If pwm01 is greater than 227... */
  {
    rc_dig_out1 = 1;           /* then output a HIGH on digital output port 1 */
    rc_dig_out2 = rc_dig_in3;  /* and map digital input 3 to digital output 2. */
  }
```

NOTE: There are differences between the pin-outs of each type of Robot Controller. This is why the full-size and EDU Robot Controllers each have a different version of code and they are not interchangeable.

4.3. Relay Outputs (FRC only)

The Relay ports on the FRC Robot Controller are all controlled by PICmicro software. The Relay outputs provide Full Forward, Full Reverse, and OFF control for motors and other devices when connected with a Spike Relay. Each relay port has 2 digital outputs. Refer to the appropriate Robot Controller Reference Manual for details on the number and location of the Relay Outputs.

Example (using the default software): Press the Trigger button on the Port 1 Joystick to put a Spike Relay connected to RLY1 in the Forward position. This would cause a motor connected to this relay to turn at its maximum speed. Press the Top button on the Port 1 Joystick to put the Spike in Reverse position, thereby reversing the motor. The relays in the example below are limited by limit switches connected to Digital Inputs 1 and 2.

Relay Digital Outputs: The relay outputs have aliases defined in the `ifi_aliases.h` file. Here is an example of how to use them.

```
/*--------- Example Aliases for Robot Controller relay outputs ----------------------------*/
#define relay1_fwd  LATDbits.LATD0
#define relay1_rev  LATEbits.LATE0
#define relay2_fwd  LATDbits.LATD1
#define relay2_rev  LATEbits.LATE1

/*--------- Example usage of relay ports --------------------------------------------------*/
/* When the switch on rc_dig_in01 is closed, the value will be 0.  */
/* This will make relay1_fwd also be 0, no matter what the value of p1_sw_trig is.  */
  relay1_fwd = p1_sw_trig & rc_dig_in01;
  relay1_rev = p1_sw_top  & rc_dig_in02;
```

4.4. Solenoid Digital Outputs (EDU only)

The solenoid outputs on the EDU Robot Controller are essentially treated as digital outputs in the software. A high, or 1, will energize (turn on) the solenoids, and a low, or 0, will shut them off.

Example (using the default software): Push the joystick corresponding to R/C PWM IN 3 forward past the programmed threshold of 160 to energize solenoid 1. Pull it backwards past 95 to energize solenoid 2. In the neutral position both solenoids will be off.

Solenoid Digital Outputs: The solenoid outputs have aliases defined in the `ifi_aliases.h` file. Here is an example of how to use them.

```
/*--------- Example Aliases for EDU Robot Controller solenoid outputs ----------------------*/
#define solenoid1       LATDbits.LATD0
#define solenoid2       LATDbits.LATD1
#define solenoid3       LATDbits.LATD2
#define solenoid4       LATDbits.LATD3
#define solenoid5       LATDbits.LATD4
#define solenoid6       LATDbits.LATD5

/*---------- R/C PWM INPUTs toggle solenoids ------------------------------*/

  if (PWM_in3 < 95)        /* PWM_in3 forward (typically) */
  {
    solenoid1 = 1;               /* turns on  Solenoid 1 */
    solenoid2 = 0;               /* turns off Solenoid 2 */
  }
  else if (PWM_in3 > 160)    /* PWM_in3 reverse (typically) */
  {
    solenoid1 = 0;               /* turns off Solenoid 1 */
    solenoid2 = 1;               /* turns on  Solenoid 2 */
  }
  else                      /* PWM_in3 neutral band */
  {
    solenoid1 = 0;               /* turns off Solenoid 1 */
    solenoid2 = 0;               /* turns off Solenoid 2 */
  }
```

5. Downloading User Code to the Robot Controller

5.1. Downloading Steps

1. Compile a valid program in *MPLAB IDE* by selecting "Make" from the "Project" menu. This will generate a `.hex` file with the same name as the project name. You may also use the `xxx_Default.hex` file which has been pre-compiled to restore the default functionality.
2. Power ON the Robot Controller.
3. Connect a DB9 Male-to-Female Pin-to-Pin cable (maximum length 6 ft.) from the PROGRAM port on the Robot Controller to PC's serial port.
4. Run the *IFI Loader* application from Start -> Programs -> IFI_Loader -> IFI_Loader.
5. Right click and select the appropriate COM port in the lower right corner of the *IFI Loader* window.
6. Click the "Browse" button and select the desired `.hex` file which you compiled from within *MPLAB IDE*.
7. (EDU RC only) Briefly press the "PROG" button on the Robot until the Program State LED becomes solid orange. Now the EDU RC is in Program Download mode. (On some PCs, this step must also be performed for the FRC Robot Controller by pressing the "Download" button.)
8. Click the "DOWNLOAD" button in *IFI Loader*. The Program State LED will blink orange.
9. When the download is complete the Robot Controller will automatically reset. There is no need to power cycle it. If the program is good, the Program State LED will blink green. A terminal window will automatically open within *IFI Loader* where any text output from the Robot Controller will be displayed.

Note: Before the new User program will start executing, an FRC Robot Controller must have a Valid RX (link) to an OI or the RC must be in Autonomous Mode.

5.2. PROGRAM STATE LED

Depending on the status of the User processor, the PROGRAM STATE LED will be green, orange, or red, and blink or stay on solid.

After programming the Robot Controller you should see the PROGRAM STATE LED flashing green. This LED indicates that the new program is running. For the FRC system you must also be linked to an Operator Interface or else this LED will be solid green and the program will not be running.

The PROGRAM STATE LED will be a solid orange if it is waiting for new user code to be downloaded. This will occur if the PROG button is briefly pressed on the Robot Controller. Pressing this button is only necessary for the EDU Robot Controller. It may also be necessary for the FRC Robot Controller on some PCs. If you are unable to download to the FRC Robot Controller, you may need to press the PROGRAM button to change the LED to orange.

While a new program is being downloaded, the PROGRAM STATE LED will blink orange.
The PROGRAM STATE LED will be red if the Master processor is unable to communicate with the User processor. This can occur if something in the User Code interferes with the inter-processor communication by writing to a reserved area.

6. Additional Programming Techniques

If you leave the serial cable connected to your Robot Controller after programming it, the routines in sections 6.1 and 6.2 can be used to print data to your computer screen. You can display the data in any serial communications terminal application. *IFI Loader* has a Terminal Window which can be used for this purpose, or you may use the application HyperTerminal. HyperTerminal is located in Start->Programs->Accessories->Communications. Settings for HyperTerminal are: Bits per second: 115200, Data bits: 8, Parity: None, Stop bits: 1, Flow control: None. You might also want to check "Append line feeds to incoming line ends" in "File->Properties->Settings->ASCII Setup…".

These commands provide a convenient way for your PICmicro program to send data to the PC screen while running. Some possible uses include debugging programs by showing you the value of a variable or expression, or by indicating what portion of a program is currently executing. Once your program has been debugged, however, you should remove all such serial text output commands so that your code will run as fast as possible in your robot. Note that printing text using these commands is relatively slow, and while this is happening no other program execution is occurring. Remember that code which takes too long to execute can cause your Robot Controller to be reset by the Master processor.

6.1. The printf() Command

The most common method to print text output to a screen in C is the printf() command. While this command is not included in the Microchip C library, IFI has implemented a limited model of printf in the `printf_lib.c` file. Please examine this file to learn the limitations of the IFI implementation as well as to see examples of how to create your own custom output modules. The default code has the following example included to get you started.

`printf()` Example: The following example demonstrates the use of a printf() command to display the decimal values of PWM OUT 7 and 8 to the computer screen.

```
printf("PWM07 = %d, PWM08 = %d\n",(int)pwm07,(int)pwm08);  /* printf example */
```

Notice that the values displayed (pwm07 and pwm08) are of type unsigned char and must be typecast as int to work with this command.

Note that the printf libraries use a significant amount of program memory space in the User processor. If the size of your program begins to bump against the 32kb ceiling of the 18F8520, you can shave off approximately 4kb from your program by removing the `printf_lib.c` and `printf_lib.h` files from your project and deleting any printf calls from your program.

6.2. Other Serial Debug Statements

While the printf() function is a standard C library, its use requires more processing power than the following utilities. The commands which follow are faster methods of printing data to a PC terminal screen, although they do not allow the flexibility and formatting of a printf statement. These commands are contained in the file `ifi_utilities.h` and can be useful for debugging your programs when execution speed is important. You may also create your own custom serial output functions using these as models.

`PrintByte` Example: The following example demonstrates using the `PrintByte` command to print bytes of data in hexadecimal format to the computer screen.

```
/*--------- Somewhere in the Main Loop ------------------------------------------------*/
      PrintByte(0xC4);    /* Print a hard-coded value. */
      PrintByte(pwm01);   /* Print a variable value. */
```

After you add these lines somewhere in the main loop, and after downloading, the *IFI Loader* will open a Terminal Window on your PC screen and wait for data from the Robot Controller. You should see "C4" and "7F" repeating, each on their own lines. "7F" should vary depending on the value of pwm01, an output variable. These lines will repeat every loop of the code. Note that if you close the Terminal Window, your program keeps executing, but you can't see the debug data anymore. You can reopen Terminal Window from the Options menu. Optionally, you can use HyperTerminal to view the data.

`PrintWord` Example: This function will print a word of data, or two bytes, in hexadecimal format.

```
/*--------- Somewhere in the Main Loop ------------------------------------------------*/
      PrintWord(0xC4A1);   /* Print a hard-coded value. */
```

You should see "C4A1" printed on your screen. A carriage return is automatically added.

`PrintString` Example: You can also print text strings using this function.

```
/*--------- Somewhere in the Main Loop ------------------------------------------------*/
    PrintString( (unsigned char *) "ERROR1\r" );   /* Print a text string. */
```

This example will display "ERROR1". The "\r" performs a carriage return. To use this function, simply replace "ERROR1" with the text you would like to print.

`DisplayBufr` Example: This function will display all 26 bytes of either the TXDATA or the RXDATA buffer. In this manner you can snoop on the data being sent to or received from the Master processor. It is a good candidate for customization so that you can display your own long buffers.

```
/*--------- Somewhere in the Main Loop ------------------------------------------------*/
    DisplayBufr( &rxdata );   /* Print the 26 bytes received from the Master processor. */
    DisplayBufr( &txdata );   /* Print the 26 bytes sent to the Master processor. */
```

This example will dump all 26 received bytes on one line before inserting a carriage return and then printing the 26 transmitted bytes with another carriage return. See what happens if you use this and move the joysticks on your control system!

6.3. Robot Feedback and User Mode (FRC only)

The FRC Robot Controller has the ability to send data back to the Operator Interface. The Robot Controller can send 11 bits every loop of the code. The data is available on the Operator Interface in three ways: 1) On the 11 Robot Feedback LEDs, 2) on the multi-segment display when in user mode, and 3) on a PC connected to the Dashboard Port. See the rc_mode_byte section (page 26) for details on writing code that can display numbers on the multi-segment display.

The Robot Feedback bits are passed from the User processor to the Master processor in the txdata packet. The Master processor then sends the data to the Operator interface via the Radio Modems. You can change the Feedback bits one at a time as in the example below.

Robot Feedback Example: The Default Code assigns aliases to the bits which control the Robot Feedback LEDs on the Operator Interface. These aliases are defined in the `ifi_aliases.h` file. The user can change these aliases.

```
/*---------- Example aliases for the ROBOT FEEDBACK LEDs ----------------------------------*/
#define pwm1_green    txdata.LED_byte1.bitselect.bit0
#define pwm1_red      txdata.LED_byte1.bitselect.bit1
#define pwm2_green    txdata.LED_byte1.bitselect.bit2
#define pwm2_red      txdata.LED_byte1.bitselect.bit3
```

The values of these LEDs (ON or OFF) are set in the Default Code in the ifi_default.c file. Here is an excerpt.

```
    if (p1_y >= 0 && p1_y <= 56)
    {           /*Joystick is in full reverse position*/
      pwm1_green  = 0;    /*Turn PWM1 green LED - OFF */
      pwm1_red  = 1;    /*Turn PWM1 red LED   - ON    */
    }
```

6.4. rc_mode_byte – Competition, Autonomous, and User Modes (FRC only)

The rc_mode_byte is a byte accessible through the GetData command. The Competition Mode, Autonomous Mode, and User Mode are all available in this byte. The Default Code already contains all the code needed to use these modes.

Competition Mode
Bit 7 of rc_mode_byte (aliased as competition_mode below) indicates the status of the Competition Control, either Enabled or Disabled. This indicates the starting and stopping of rounds at the competitions. Competition Mode is indicated by a solid "Disabled" LED on the Operator Interface. When Disabled, all PWM and Relay outputs are disabled, but program execution continues. competition_mode = 1 for Enabled, 0 for Disabled.

Autonomous Mode
Bit 6 of rc_mode_byte (aliased as autonomous_mode below) indicates the status of the Autonomous Mode, either Autonomous or Normal. This indicates when the robot must run on its own programming. When in Autonomous Mode, all OI analog inputs are set to 127 and all OI switch inputs are set to 0 (zero). Autonomous Mode is indicated by a blinking "Disabled" LED on the OI. autonomous_mode = 1 for Autonomous, 0 for Normal.

Autonomous Mode can also be turned ON by setting the RC to Team 0 (zero) tethering to an OI with its team number set to 0. Note that if competition_mode = 0 (Disabled), then Autonomous Mode is also disabled.

User Mode
Bit 5 of rc_mode_byte (aliased as user_display_mode below) indicates when the user selects the "User Mode" on the OI. PB_mode.bit5 is set to 1 in "User Mode". When the user selects channel, team number, or voltage, user_display_mode is set to 0. When in "User Mode", Robot Feedback LEDs are turned off and the value stored in txdata.LED_byte1.data is displayed on the multi-segment display on the Operator Interface. In the default code this is set to the value of Port 1 Y-Axis.

Note: "User Mode" is identified by the letter “u” in the left digit (for 4 digit OI's)
Note: "User Mode" is identified by decimal places on the right two digits (for 3 digit OI's)

Autonomous _Mode Example: This example shows portions of the code that reference rc_mode_byte. The Perform Operations Section below uses aliases based on rc_mode_byte bits to execute different sections of code.

The following three aliases are declared at the end of the ifi_aliases.h file:

```
#define user_display_mode rxdata.rc_mode_byte.mode.user_display
#define autonomous_mode rxdata.rc_mode_byte.mode.autonomous
#define competition_mode rxdata.rc_mode_byte.mode.disabled
```

For code you wish to have run in Autonomous mode, you must edit the User_Autonomous_Code() routine in the user_routines_fast.c file. Here is an excerpt from main.c which calls the autonomous code:

```
      if (autonomous_mode)         /* DO NOT CHANGE! */
      {
        User_Autonomous_Code();    /* You edit this in user_routines_fast.c */
      }
```

User Mode Example: This example shows the Default Code that changes the data sent to the Operator Interface when the user sets the Operator Interface to User Mode.

```
if (user_display_mode == 0) /*User Mode is Off  */
{
                    ...
                /* This section of code deleted for this example. */
                    ...
} /* (user_display_mode = 0) (User Mode is Off) */

else  /* User Mode is On */
{
  txdata.LED_byte1.data = p1_y;   /* Change p1_y to a value in which you are interested. */
}
```

6.5. Simulator Mode in MPLAB

For the experienced user, it is possible to simulate the code you write on the computer without having to actually download it to your Robot Controller. This is can be very useful for debugging purposes. Here is how you set it up with your project file open in MPLAB:

1. First you must select "Debugger -> Select Tool -> MPLAB SIM" from the menu in MPLAB.
   - Notice the new buttons which appear in the toolbar at the top of MPLAB.
2. Next you must select "Project -> Build Options… -> Project" from the menu.
3. Click on the "MPLAB C18" tab.
4. In the "Macro Definitions" area, click the "Add…" button.
5. Type "_SIMULATOR" in the popup box and click "OK".
6. Click "OK" in the "Build Options" window.

Now after you re-compile your code (Project -> Build All), you can use the new Debug buttons in the toolbar to step through your code, while keeping an eye on variables and registers using selections from the "View" menu. You can also dynamically change their values with these tools to simulate your robot's actual operation.

For example, right-click on a line you wish to stop at and select "Set Breakpoint". Now click the "Run" button on the toolbar. The code will execute and if it reaches your breakpoint it will pause. You can then select "Watch" from the "View" menu and select a variable you are interested in. If you double-click on its value you will be able to change it by typing. Then you can continue the program execution by clicking the "Run" button again, or with the "Step Into" or "Step Over" buttons. You can also set multiple breakpoints at different points in your code. Using these techniques you can follow your program's flow and logic, as well as testing it with different stimuli before you ever download it to the real Robot Controller. Be aware that all inputs and outputs, including the entire input stream from the Master processor will be set to zero upon startup in simulator mode.

For more instructions on simulator mode, please refer to the MPLAB C18 C Compiler Getting Started document (Section 3.3.7 on page 29).

7. PICmicro Commands

Not all features of the 18F8520 PICmicro can be used by the user who is writing custom code for the Innovation First Control System. Certain registers are reserved because they are used to allow the User processor to function within the embedded system. Modification of these registers may result in improper operation or in the Robot Controller not functioning at all.

The following list contains the most common and useful features of the 18F8520 which are accessible to the user when programming the Robot Controller:

- all timer modules
- all CCP modules
- all analog modules (ADC, comparators, etc.)
- all EEPROM memory
- most low priority interrupt sources
- USART1 (PROGRAM port, RS-232)
- USART2 (TTL Serial Port)

Refer to the file `ifi_picdefs.h` to find out which registers and bits are reserved by the system, or are not available to the user. It is not necessarily comprehensive, since many registers have multiple functions, some of which may be allowed, while others are not. For a complete pin list of the usable pins which you can access in your code, please refer to the appropriate Robot Controller user guide.

If your Robot Controller ceases functioning after a program change, you should revert back to the last known working version and then incrementally add back in the new code until you find what caused the problems. It is good programming practice to keep an archive of old code so that you can do this. Many programmers use some form of version control and there are lots of tools for software configuration management to choose from.

8. References

The following useful documents can be found at Microchip's web site (http://www.microchip.com):

PIC18FXX20 Data Sheet	Document #: DS39609A
MPLAB IDE v6.xx Quick Start Guide	Document #: DS51281C
MPLAB C18 C Compiler Getting Started	Document #: DS51295B
MPLAB C18 C Compiler User's Guide	Document #: DS51288B
MPLAB C18 C Compiler Libraries	Document #: DS51297B

Information specific to each respective Robot Controller model can be found in these documents from Innovation First's web site (http://www.innovationfirst.com):

EDU 2004 Robot Controller Reference Guide
FRC 2004 Robot Controller Reference Guide

An authoritative C programming book:

Kernighan, B. W., & Ritchie, D. M. (1988). *The C Programming Language (2nd Edition)*. Prentice Hall PTR. ISBN: 0131103628.