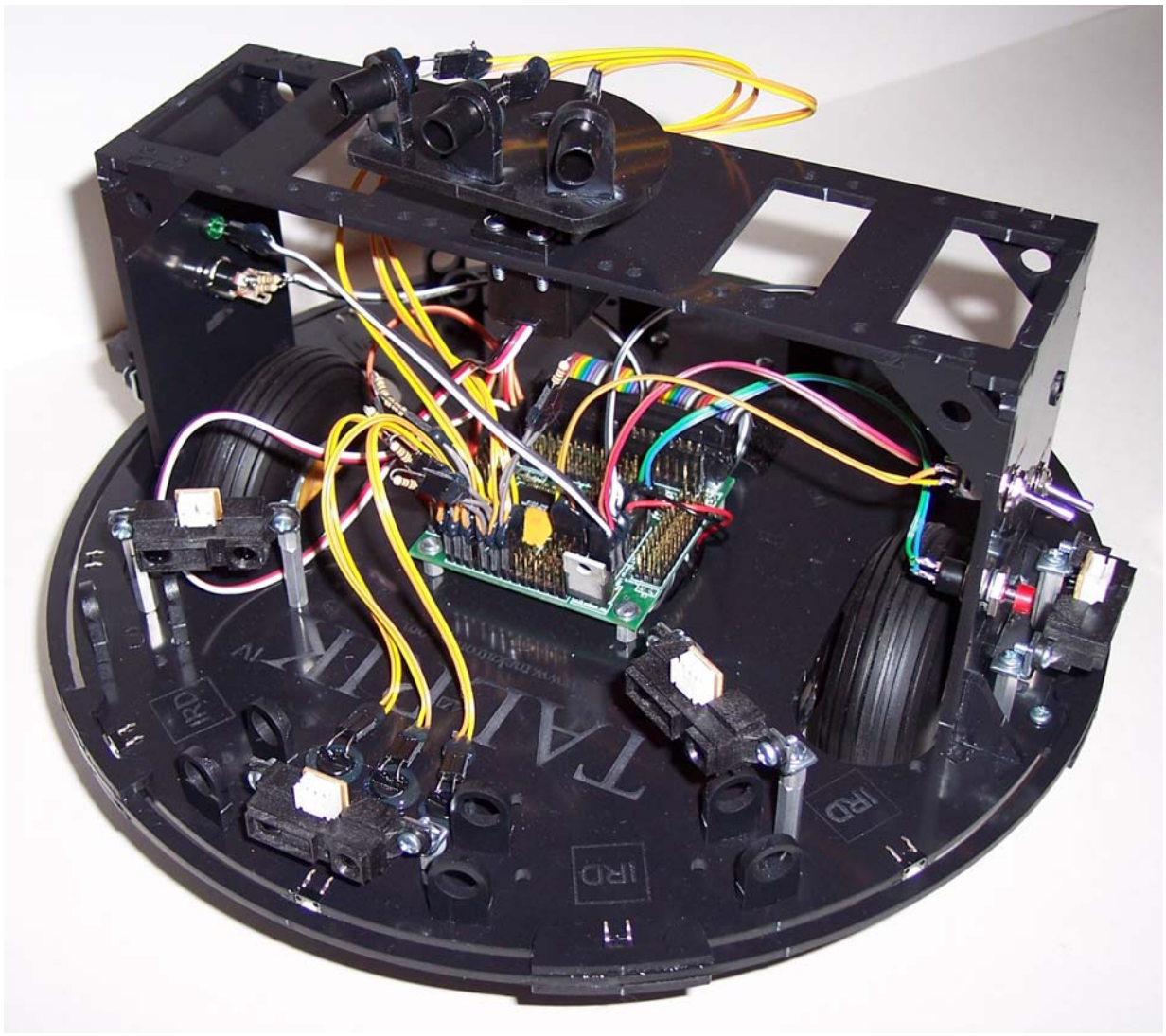
TALRIK-IV Users Manual

by

Keith L. Doty

Version 01



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MANIFESTO

Mekatronix™ espouses the view that the personal autonomous agent will usher in a whole new industry, much like the personal computer industry before it, if modeled on the same beginning principles:

- Low cost,
- Wide availability,
- Open architecture,
- An open, enthusiastic, dynamic community of users sharing information.

Our corporate goal is to help create this new, exciting industry!

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1. SAFETY AND HANDLING

1.1 TALRIK-IV™'s Static Sensitive Parts

Some of *TALRIK-IV*™'s components are static sensitive. These are located on the printed circuit boards. Do not touch these boards without being properly grounded. Static discharge can destroy these parts.

1.2 Caution for Biological Organisms

Most individuals find *TALRIK-IV*™, exciting, enjoyable, amusing, and fascinating. *TALRIK-IV*™'s small size minimizes its threat to organic life, although pets and small children might find *TALRIK-IV*™ either an interesting playmate or an alien to avoid. A child's hands, feet, and mouth probing *TALRIK-IV*™ may lead to minor injury to both child and robot, so, to eliminate adverse reactions with pets, children, or nervous adults, be sure *TALRIK-IV*™ operates under supervision by someone who knows how to turn it off. Remember, *TALRIK-IV*™ is an autonomous machine and, as such, becomes "out of control"[1] once set in motion.

1.3 Holding, Carrying, and Transporting TALRIK-IV™

TALRIK-IV™'s small size and portability make it ideal for safe demonstrations and presentations of machine intelligence algorithms. Porting *TALRIK-IV*™ from desk-top platform to floor and back, the most frequent carrying operation, requires handling *TALRIK-IV*™ carefully. The recommended carrying technique is to firmly hold *TALRIK-IV*™on both sides at the base of the bridge supports next to the wheels with fingers curled underneath the robot and thumbs on top. Other carrying techniques can be devised by users at their own risk.

To transport *TALRIK-IV*™ for long distances, place it securely padded into a suitably sized box. Do not expose *TALRIK-IV*™ to extreme cold or heat in an automobile during winter and summer for more than a few hours. Although *TALRIK-IV*™ has survived a hot automobile for 12 hours in *40°C*, such treatment cannot help but reduce its lifetime.

TALRIK-IV™ has flown in airline luggage compartments across the Atlantic, shipped by U.S. Mail, and ridden in automobiles across the United States and Europe in all kinds of weather! The following caution, however, is our official advisement.

Caution: *TALRIK-IV™ should not be exposed to moisture, or continuous high humidity (>90%), or high temperatures, 40°C (100°F), or low temperatures, 5°C (40°F).*

1.4 Storage

Place *TALRIK-IV*™ in a labeled (don't forget where "it" is), enclosed, sealed, padded box in an office or home environment when storing for extended periods of time.

[1] Wireless versions have remote control capabilities.

2. GETTING *TALRIK-IV*™ READY

This section tells you how to unpack and prepare *TALRIK-IV*™ for operation.

2.1 Unpacking An Assembled TALRIK-IV™

1. Carefully unwrap *TALRIK-IV*™ from the bubble wrap. Be careful not to catch wires or drop the robot.
2. Make sure that no cables have become disconnected from the robot during shipment. If cables have disconnected, refer to the *TALRIK-IV*™*Assembly Manual* for reconnection instructions. Clear the bumper if it appears to be jammed against any of the bumper switches. If it is, just gently shift the bumper away from the switch. Latter program testing will reveal any specific problems.
3. Download software from the vendor who sold it to you. Download *TALRIK-IV*™ documentation on-line from <www.mekatronix.com>. You can purchase a CD containing any purchased software and all the *TALRIK-IV*™manuals at any time.

The following must be purchased separately

4. A wall plug adapter for recharging the robot,
5. An *MB2325* serial communications board and cable,
6. Six AA, Nickel-Cadmium rechargeable batteries. DO NOT USE ALKALINES.

2.2 Nickel-Cadmium Batteries Required

TALRIK-IV™ requires a minimum of six AA Nickel-Cadmium (*NiCd*) rechargeable batteries Mekatronix™ recommends our own high capacity (800mah) AA *NiCd* batteries.

Only use nickel-cadmium AA batteries. A 6-pack of batteries that produce more than 1.2volts per cell will produce too much voltage and will damage attached servos. For example, alkaline batteries produce 1.5volts per cell and, therefore, must not be used.

The battery pack is located in front of the rear caster on the underneath side of the robot.

NiCad batteries sustain useful power until just before they become fully discharged. So, if you see *TALRIK-IV*™ really slowing down, it is time to recharge it!

2.3 Recharging Batteries

TALRIK-IV™'s AC adapter output must be rated at 12 volts D.C. and be able to supply 300 milliamps at that rating. Lower voltages will not charge the batteries and higher voltages my damage the electronics. The charger plugs into the receptacle mounted on the left bridge support. When not in use, keep *TALRIK-IV*™ connected to the charger with the power off. If power is left

on while charging, the batteries will discharge completely after a few hours as the current load of the electronics exceeds the charge current.

A Mekatronix AC adapter plugs into the charge jack receptacle on the *Left Bridge Support* of the *TALRIK-IV™*. The charging technique uses a trickle charge. This means that a small current is constantly applied to the batteries. Because this is a low level current the robot can be left charging indefinitely. While the robot is not moving around plug it into the charger, especially while programming the robot on your desktop. This will extend operating time for programming.

2.3.1 If you purchased Charger and Batteries:

1. Plug the Mekatronix AC adapter into a power socket and insert the 12 volt DC output power plug into the power jack on the left bridge support of a completely assembled robot. The green LED charging indicator should light.
2. Place the two toggle switches on the robot in *POWER-SAVE* and *DOWN-LOAD* mode, respectively.
3. Wait 6 hours for the batteries to become fully charged.

*2.3.2 Installing or Replacing Batteries (**IMPORTANT: AA NiCad Rechargeable only**)*

1. Place the robot switch into *POWER-SAVE* mode.
2. With the *Sensor Head* fully forward, carefully and gently, flip *TALRIK-IV™* over so it leans on the back edge of the *Bridge Top*.
3. Unhook the snap connector from the battery 6-pack.

WARNING! WARNING! WARNING!

DO NOT ACCIDENTLY OR OTHERWISE REVERSE THE BATTERY PACK SNAP CONNECTIONS OR YOU MAY DAMAGE THE ELECTRONICS.

4. Unfasten the Velcro™ battery pack strap and remove the pack.
5. Replace with a second pack of fully recharged batteries or place six, fully charged, AA, NiCad batteries into the old battery pack, oriented with proper voltage polarity as labeled on the pack. Failure to do the latter may damage the electronics.
6. Attach the battery pack tightly with the Velcro™ strapping. Fasten the snap connector onto the battery pack terminals CAREFULLY! Accidentally touching the battery pack terminals with reversed snap connectors may damage the electronics. Remember, even though the snap connector will fit only one way onto the battery pack, this mechanical keying does not protect against accidental reversal of the terminal voltages by slight, simultaneous contact of the snap connectors on the wrong terminals.

3. *TALRIK-IV™* OVERVIEW

This section provides the user general orientation to *TALRIK-IV™*.

3.1 What Can TALRIK-IV™ DO?

*TALRIK-IV™*provides a platform for the development and testing of machine intelligence and autonomous behavior algorithms. The creative and entertainment value of developing your own intelligent, physically embodied autonomous agent provides tremendous motivation and pleasure. As with most high-tech tools (toys!) the implications have broad scope. By attaching different mechanisms to such an autonomous agent, the user can develop autonomous vacuum cleaners, autonomous lawnmowers, autonomous construction vehicles, autonomous butlers or maids, intelligent kinesthetic art, tile laying robots, security robots, maintenance robots, space station robots, planetoid explorers, undersea mining, rescue vehicles, war robots, and so on. As the community of autonomous robot developers increases, the applications coming forth will be legion, many of which may be totally surprising.

Mekatronix offers a number of sensor kits and mechanisms to enhance the *TALRIK-IV™* range of applications. In particular, the ARGOS provides IR proximity sensors, photoresistors and sonar on a pan-tilt head that mounts directly on the bridge. You can also purchase more IR Range sensors and mount them on the bridge, fore and aft, or at the 12 clock positions on the robots *Top Plate*.

3.2 Operating Environment

TALRIK-IV™ is designed to operate in an office or home environment with smooth floor surfaces. Although *TALRIK-IV™* can handle short pile rugs, it spends more energy overcoming rug friction than smooth floor friction and its operational lifetime on a battery charge reduces considerably. Shag rugs and extremely rough surfaces are inimical to *TALRIK-IV™*and should be avoided.

In general, operating environments comfortable to lightly clothed humans will probably be suitable for *TALRIK-IV™*. However, we reiterate the previous caution on environmental constraints.

Caution: *TALRIK-IV™ should not be exposed to moisture, or continuous high humidity (90%), or high temperatures, 40° C (100°F), or low temperatures, 5°C (40°F).*

3.3 Physical Orientation

TALRIK-IV's™ wheel axis determines the robot's left-to-right axis. The diameter perpendicular to the wheel axis determines the front-to-back axis. The "TALRIK-IV" label appears on the front of the robot's *Top Plate*. The left and right side of the robot is determined from the handedness of a driver sitting on the bridge facing forward. The control switches, therefore, are on the right side of the robot and the charge jack on the left side. The caster wheel is at the rear of the robot, near the battery pack on the underneath side of the *Top Plate*. Locations around the *Top Plate* of

the robot are designated by clock positions. Front-center defines 12 o'clock and the *Left Bridge Support* defines 9 o'clock. From these o'clock definitions you can determine the remainder clock positions on the *Top Plate*. For example, the *Right Bridge Support* is at 3 o'clock.

3.4 Sensor Layout

The drawing in Figure 1 points out the standard layout of TALRIK-IV's sensor suite which includes five IR range sensors and six photoresistor light sensors, three on the *Top Plate* for line-following and three on the *Sensor Head* to detect ambient light conditions. The floating bumper is sensualized with 10 switches, five for the front bumper at 10, 11, 12, 01, 02 o'clock and five for the rear bumper at 4, 5, 6, 7, 8 o'clock.

Mekatronix provides additional sensors kits for mounting on the robot. Check a Mekatronix distributor.

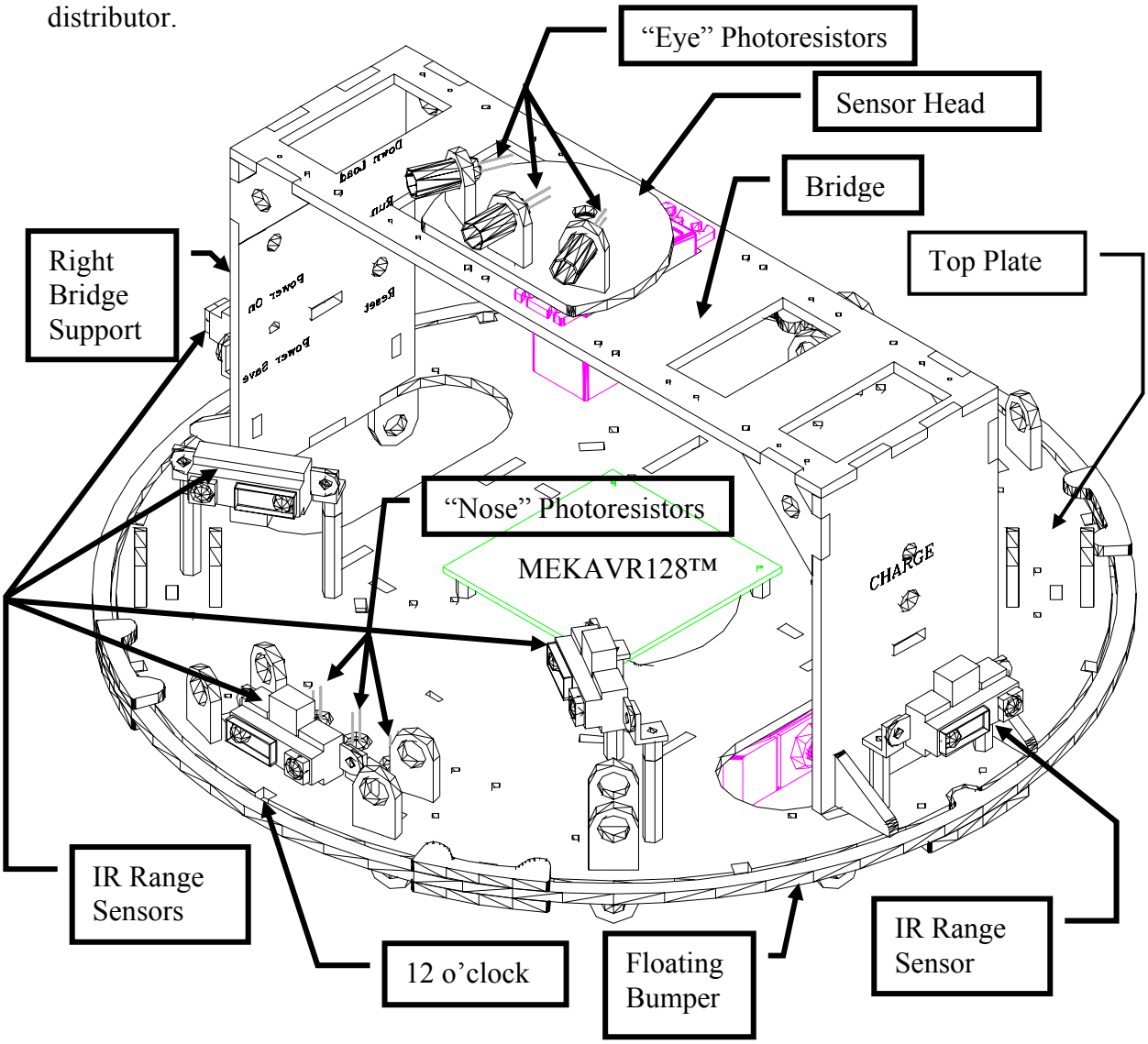


Figure 1. This 3-D drawing locates the standard sensor complement of a *TALRIK-IV*™, namely, five IR range sensors and six photoresistor light sensors, three on the *Top Plate* for line-following and three on the *Sensor Head* to detect ambient light conditions. The floating bumper is sensualized with 10 switches, five for the front bumper at 10, 11, 12, 01, 02 o'clock and five for the rear bumper at 4, 5, 6, 7, 8 o'clock.

3.5 Program Access to Sensor Readings

Each *TALRIK-IV*™ sensor has an index *i*, $0 \leq i \leq 28$, assigned to it. The index *i*, along with the standard library function `analog(i)`, allows a program to read the output of sensor with index *i*. Column-1of **Table 1** specifies the index of the sensor described in Column-2. The last column indicates defined label(s) for each sensor. A program can access a sensor's value either through the function `analog(i)`, as mentioned, or through the label defined (`#define`) for that sensor in the last column of the table. The include file `tkIVavr.h` in directory `Include_Meka` provides a complete description of sensor definitions, as well as motors, servos and TALRIK-II™ legacy functions.

Table 1 Program Access to *TALRIK-IV*™ Sensors

Sensor Index	MEKAVR128 Header	SENSOR DESCRIPTION	PROGRAM ACCESS `analog(Sensor Index)` or Associated Program Defines
0	MUX16	Argos Left IR detector	`#define LIRA analog(0)`
1	MUX17	Left Eye Photoresistor (Argos)	`#define ECDSL analog(1)`
2	MUX18	Middle Eye Photoresistor (Argos Sonar)	`#define ECDSM analog(2)`
3	MUX19	Right Eye Photoresistor (Argos)	`#define ECDSR analog(3)`
4	MUX20	Argos-Head Right IR detector	`#define RIRA analog(4)`
5	MUX21	Left Nose Photoresistor (Line Follow)	`#define NCDSL analog(5)`
6	MUX22	Middle Nose Photoresistor (Line Follow)	`#define NCDSM analog(6)`
7	MUX23	Right Nose Photoresistor (Line Follow)	`#define NCDSR analog(7)`
8	MUX8	User Defined	`#define SENSOR8 analog(8)` `#define IR08 analog(8)`
9	MUX9	IR range sensor at 9 o'clock	`#define IRDL analog(9)` `#define IR09 analog(9)`
10	MUX10	IR range sensor at 10 o'clock	`#define IRDFL analog(10)` `#define IR10 analog(10)`
11	MUX11	User Defined	`#define SENSOR11 analog(11)`

			`#define IR11 analog(11)`
12	MUX12	IR range sensor at 12 o'clock	`#define IRDFM analog(12)` `#define IR12 analog(12)`
13	MUX13	User Defined	`#define SENSOR13 analog(13)` `#define IR01 analog(13)`
14	MUX14	IR range sensor at 2 o'clock	`#define IRDFR analog(14)` `#define IR02 analog(14)`
15	MUX15	IR range sensor at 3 o'clock	`#define IRDR analog(15)` `#define IR03 analog(15)`
16	ADC2	User Defined	`#define SENSOR16 analog(16)`
17	ADC3	User Defined	`#define SENSOR17 analog(17)`
18	ADC4	User Defined	`#define SENSOR18 analog(18)`
19	ADC5	User Defined	`#define SENSOR19 analog(19)`
20	ADC6	User Defined	`#define SENSOR20 analog(20)`
21	MUX0	Battery Level	`#define BATTERY analog(21)`
22	MUX1	Battery Charging	`#define CHARGE analog(22)`
23	MUX2	Rear bumper	`#define REAR_BUMP analog(23)`
24	MUX3	Front bumper	`#define FRONT_BUMP analog(24)`
25	MUX4	User Defined	`#define SENSOR25 analog(25)` `#define IR04 analog(25)`
26	MUX5	User Defined	`#define SENSOR26 analog(26)` `#define IR05 analog(26)`
27	MUX6	IR range sensor at 6 o'clock (Optional)	`#define IRDBM analog(27)` `#define IR06 analog(27)`
28	MUX7	User Defined	`#define SENSOR28 analog(28)` `#define IR07 analog(28)`

The 12 clock positions on the *Top Plate* have legacy Infrared sensor assignments. These IR sensors can be IR range or proximity detectors, depending on user configuration, and have program definitions `#define IRxx`, where $01 \leq xx \leq 12$. The basic *TALRIK-IV™* provides only for 5 IR range sensors at clock positions 9, 10, 2, 3 and the fifth one placed at user discretion, for example, at 12 o'clock, at 6 o'clock, or hanging centered from the *Bridge* facing forward. The IR range sensors at 10 and 2 o'clock must be cross-eyed to provide adequate collision avoidance capability. Other sensors can be purchased and added later.

The C-Language analog functions

```
void analog_init(void);
int analog(unsigned char sensor_number);
```

are contained in library archive `libmeka.a` , which is found in directory `Lib_Meka`. Before using the function `analog( )`, a program must first execute the function `analog_init()` to initialize

the *MEKAVR128*™ analog-to-digital converter. This initialization is include in the definitions `ROBOT_INIT` and `ROBOT_AND_SERIAL_INIT` (*Section* 3.6).

3.6 Robot Program Initialization

The initialization of the analog-to-digital converter mentioned in the previous section is part of a more general robot initialization. Before any computer program can use the resources of the robot, various functions must initialize the appropriate hardware configuration. Two such initializations are common,

1. `ROBOT_INIT`
2. `ROBOT_AND_SERIAL_INIT`

where

```
#define ROBOT_INIT {analog_init(); sei(); clock_init(); servo_init();
                        eeprom_servo_limits_init(); waveform_init();}
```

and

```
#define ROBOT_AND_SERIAL_INIT { usart0_init(); analog_init(); sei();
            clock_init(); servo_init(); eeprom_servo_limits_init();
            waveform_init();}
```

are found in header file `mekatronix_avr.h`.

Here is what each function does with respect to the robot's *MEKAVR128*™ microcontroller,

`usart0_init()` Initializes serial communications on usart0
`analog_init()` Initializes the analog-to-digital converter
`sei()` Globally enables interrupts and must be executed before the next three functions in this list.
`clock_init()` Enables the interval timer,
`servo_init()` Initializes servo control on the servo bus,
`eeprom_servo_limits_init()`
Transfers default values of `servo_limits[MAX_SERVO][2` from eeprom, if previously stored there, otherwise from initialization of `servo_limits[MAX_SERVO][2]` in <servo.h>.
`waveform_init()` Enables square wave generation on FM1 to FM8 headers.

If the program application requires no serial communication, make `ROBOT_INIT;` your first non-definition statement in `int main(void).` If the program requires asynchronous serial communication make this statement `ROBOT_AND_SERIAL_INIT`. Of course, if you write programs that use only a subset of the resources, only that subset need be initialize. Just remember, however, that `sei()` must be executed if the program uses the interval timer, servo or waveform functions.

3.7 Digital IO

While the standard base kit of the *TALRIK-IV*™ does not possess any digital IO, except the DOWNLOAD/RUN mode switch on PE4, the robot's MEKAVR128™ microcontroller provides 23 digital IO pins for extended applications:

1. PE2, PE3, PE5, PE6, PE7;
2. PB0, PB1, PB2, PB3, PB5, PB6, PB7;
3. PG3, PG4;
4. PORTD (PD0 to PD7)

These pins come out to three pin male headers with (Pin_Signal, Regulated_Power, Ground) to make interfacing easy.

3.8 Frequency Modulation using Square Waves

Eight, two-pin male headers, labeled FM1 to FM8, all produce the same, program-specified square-wave coming from PB4. The default frequency is 40KHz, but the programmable frequency range is 16Hz to 4MHz. The square-wave generation facility can also be turned off under program control.

Whatever is connected across an FM header will also be in series with a 330 Ohm resistor. Connect an IR or visible LED directly across an FM header and you have modulated light at the program frequency. All eight of the FM connections, however, will modulate at the same frequency.

The header file `<waveform.h>` provides two functions, `waveform_init()` and `waveform_frequency_change(long freq)`. The first function must be executed only once to initialize the waveform generation on the FM headers. The second function allows you to specify the frequency of the square-wave. The macros `WAVE_OFF` and `WAVE_ON` permit you to turn the waveform generation off and on.

3.9 TALRIK-IV's™ Bridge

TALRIK-IV's™ horizontal cross piece, referred to as the *bridge*, supports, in the basic configuration, a servo driven sensor head with three cadmium sulfide cell photoresistors. These photoresistors allow *TALRIK-IV*™ to sense different ambient light levels or follow beacons. The pan-tilt ARGOS™ sensor head can also be installed on the bridge as an accessory.

The bridge allows extensive sensory and servo expansion capabilities. The bridge supports the following arrangements of servos and microcontrollers: 1) five servos, 2) four servos and a *MEKAVR128*™, 3) three servos and two *MEKAVR128*™s, or 4) two servos and three *MEKAVR128*™s. The bridge can also be used to support small laptop computers or personal data assistants (PDAs) configured to perform computer vision and artificial intelligence operations for the robot. As mentioned previously, you can also hang various sensors from the bridge.

3.10 Switches

TALRIK-IV™ provides easy access to the robot control switches on the right bridge support.

The red *RESET* button resets the *MEKAVR128™* microcontroller.

The *POWER-SAVE/ON* toggle switch in the *POWER-SAVE* position completely disconnects the battery from the electronics and should rightfully be called *POWER-OFF*. A fully charged battery pack will last indefinitely in *POWER-SAVE (POWER-OFF)* position. In the *POWER-ON* position the red LED indicator lights.

In *DOWN-LOAD* mode the *DOWN-LOAD/RUN* toggle switch permits the downloading of programs with Mekatronix's proprietary loader stored permanently within the *MEKAVR128™* boot flash memory. In *RUN* mode, a press of the reset button will invoke the start-up of the most recent program loaded into *TALRIK-IV™*.

3.11 Can you Physically Damage TALRIK-IV™ with Software?

The answer is YES! A program that commands the robot to oscillate between 100% forward and 100% backward for 30 seconds or more may overheat, and possibly burn out, the servo drive electronics. Anytime your program controls servos and motors, you should take extra care to insure this type of behavior does not occur.

WARNING!

Rapid oscillations of motor direction and speed for extended periods of time will burn out the motor control electronics.

3.12 Controlling TALRIK-IV™s Motors

The library function `motor_hs(which_motor,speed)` controls the wheel motors. The parameter `which_motor` specifies either the left or right motor and `speed`, $-100\% \leq speed \leq 100\%$, drives the wheels forward with a positive percentage and in reverse with a negative percentage of maximum forward or reverse speed, respectively. Unfortunately, the motor speeds do not really specify percentage of maximum, as the motor driver electronics exhibits extreme non-linearity. Further, as the batteries drain, the voltage drops and the robot motors move slower, at any specified percentage, than with fully charged batteries. Eventually the batteries discharge to a point that the motors stop, regardless of the percentage specified.

For smoother operation change motor speeds gradually. When you program smooth motor control, the robot motion looks more "organic".

3.13 Floating Bumper™[2]

TALRIK-IV™'s floating bumper slides on and is held into place by four bumper guides at 1, 5, 7, and 11 o'clock and two bumper clips at 9 and 3 o'clock. While bumper provides coverage and protection around the edge of the *Top Plate*, the rest of TALRIK-IV's™ is vulnerable to small objects lower than TALRIK-IV's™ platform or projections above the top plate. Such obstacles do occasionally exist in home and office, and can stall the robot when it strikes them. A stalled robot is not a pleasant thing to watch or hear! The wheels struggle to turn and could burn out the wheel motors if the surface has high friction. I recommend, as general rules, to 1) *TALRIK-IV™* proof such obstacles and to 2) Hang around and get it out of trouble.

3.14 Serial Communication from Host Computer to Robot

This section assumes *TALRIK-IV™* has fully charged batteries and the processor functions. Without either of these prerequisites, the user cannot begin.

The *MB2325* serial communications board (Figure 2) generates the proper voltage conversions that permit the user to download code and data to *TALRIK-IV™* and upload data from the *TALRIK-IV™* via a 6-wire serial communications link. Whenever testing programs on *TALRIK-IV™*, the host computer links with the *TALRIK-IV™* via this interface or an equivalent wireless option. For the standard serial link, rather than duplicate the *MB2325* interface circuit on each robot, Mekatronix™ uses a single external interface for the host computer. This approach has a twofold advantage, 1) it reduces the amount of circuitry on the robot platform, reducing battery energy consumption and printed circuit board cost, 2) only one *MB2325* board is required per computer instead of one per robot. In multiple robot systems, or swarm systems, this approach yields an increasing cost advantage.

The photograph (Figure 3) illustrates a complete serial hookup between a *TALRIK-IV™* and a host computer.

At one end, a six wire communications cable (Mekatronix part number *C2325*, type F6W6F6) inserts into a 6-pin header on the *MB2325* bi-directional serial communications board and to the 6-pin, serial-interface header `USART0/PROG` on the *MEKAVR128™* microcontroller board. A 4 inch long "pig-tail" extension of the `USART0/PROG` header (Figure 4) makes the header easier to access for the frequent plugging and unplugging the 6-wire *C2325* cable from the robot.

The *MB2325* connects directly into *COM1* port of older personal computers with 25-pin D25 connectors. Current computers have a 9-pin D9 connector, so you will need to acquire a D25 to D9 serial modem cable to be able to connect *COM1* to the *MB2325* board.

If the host computer only has USB connections, you will need a hardware dongle to convert from USB to RS232C. The output of the dongle will then drive the *MB2325* normally.

[2] *Floating Bumper™* © Mekatronix™

Whether downloading code or data, the host computer always communicates with the robot at 115.2KBaud on the serial communication link described above. An ANSI terminal emulator program, such as HyperTerminal™ for WINDOWS, on the host computer provides the software interface to the hardware communication link.

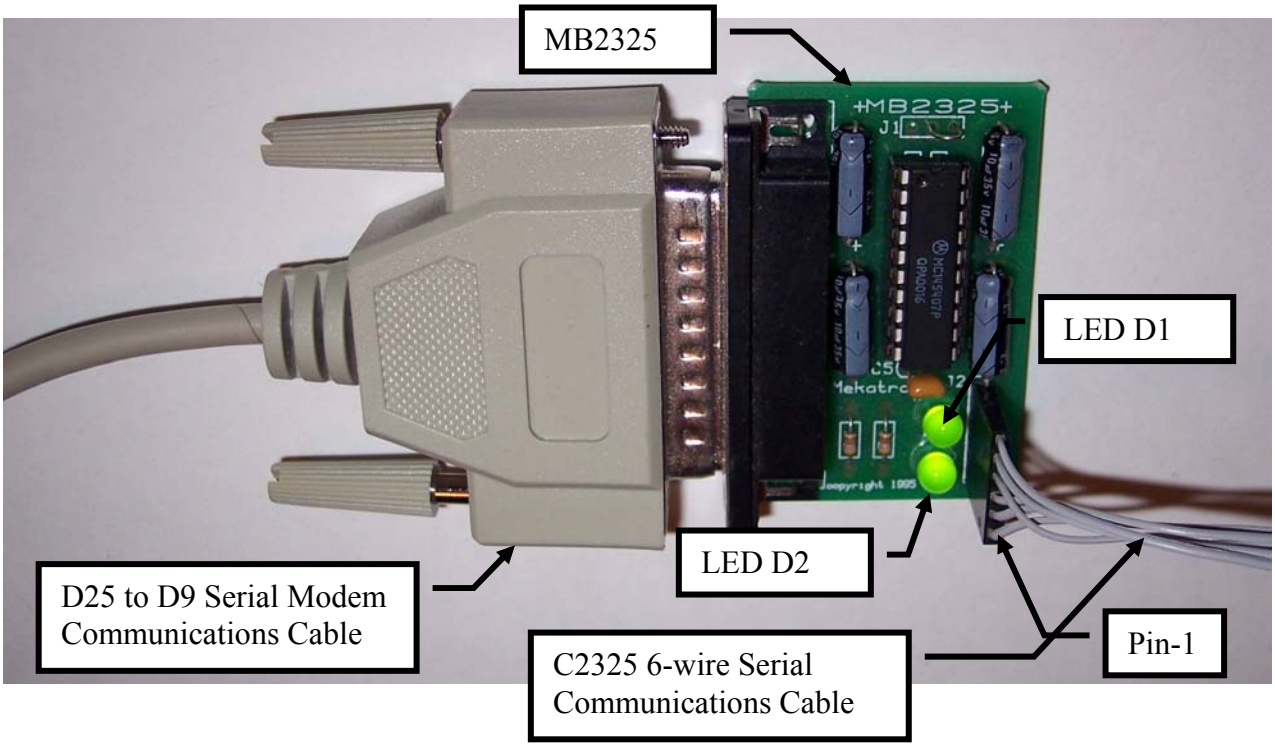


Figure 2. Serial communications between the *TALRIK-IV™* robot and a host personal computer using RS232C protocol requires a voltage conversion device, the Mekatronix *MB2325* board, to translate RS2325C voltages from the host computer to the 5 volts and ground expected by the robot's microcontrollers serial port USART0. Both LEDs are lit in the photograph, indicating a proper serial connection between host computer and robot.

3.14.1 COM port problems to avoid

A terminal emulator program locks the *COM* port to which you assign the program and should release the port upon its termination. Some older emulators might not be programmed to release

the port upon termination and, thus, hang up your *COM* port and prevent you from reopening it without a computer restart. If this is the case, find a more recent terminal emulator that obeys current system protocol!

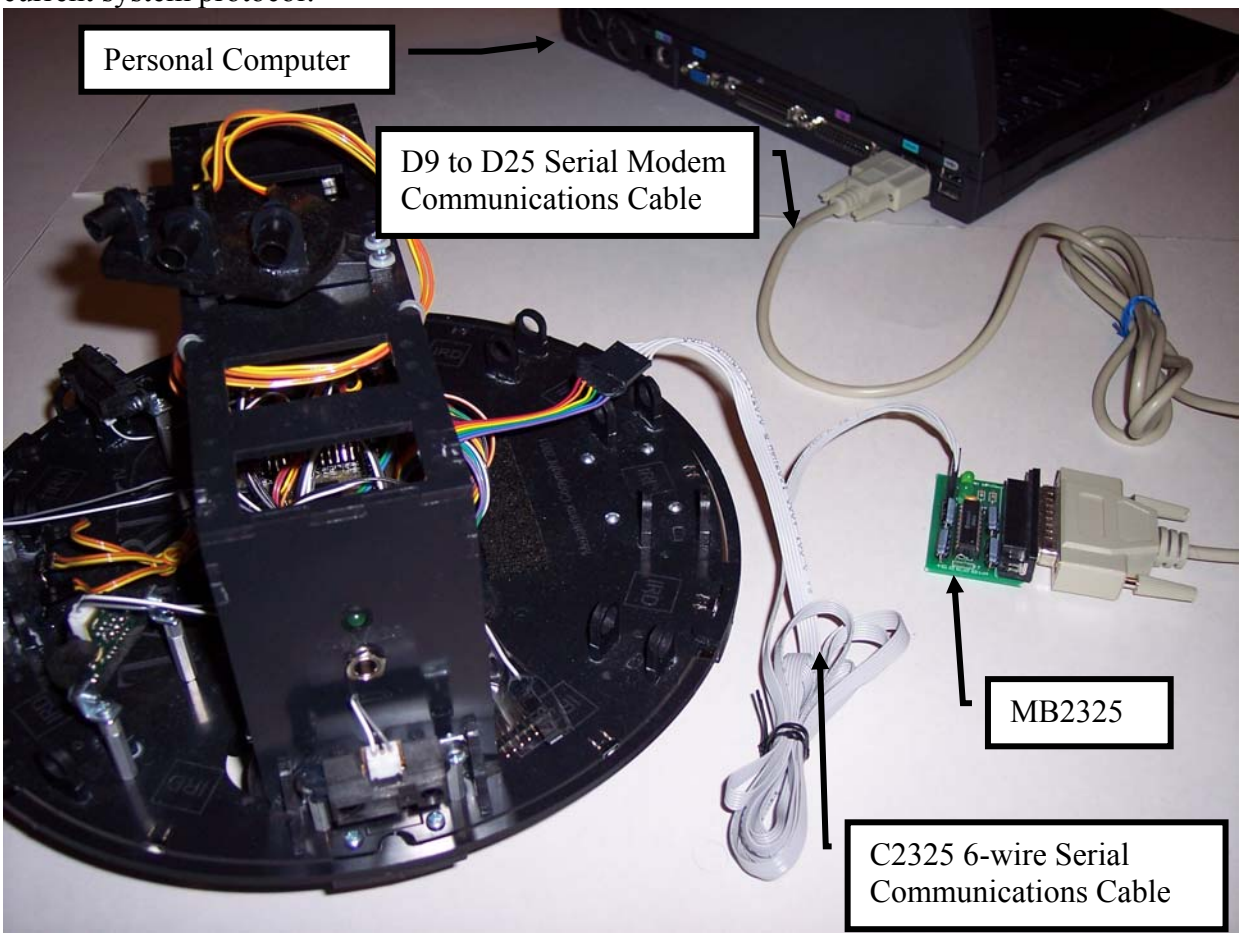


Figure 3. Serial communications between the *TALRIK-IV™* robot and a host personal computer requires a Mekatronix D25 to D9 serial modem cable (Part DB9RS232MC), a Mekatronix *MB2325* Communications board, and a Mekatronix *C2325*, 6-wire serial cable. The modem cable connects a *COM* port on your computer to the *MB2325*. The *C2325* cable connects the *MB2325* to the 6-pin USART0 header on the *MEKAVR128™*.

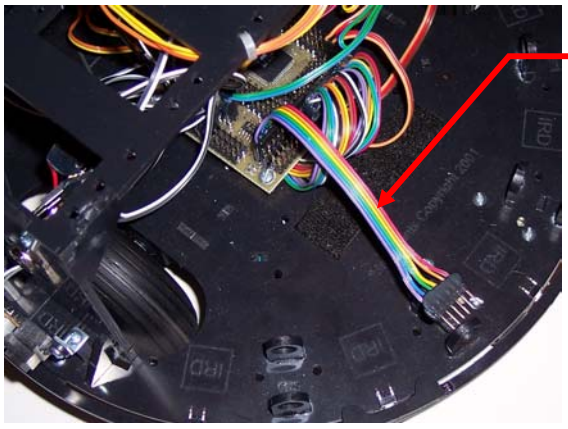


Figure 4. A 6-wire "pig-tail" brings out the 6-pin *MEKAVR128™* header USART0/PROG to make it easily accessible for plugging and unplugging the *C2325* serial cable into the header. The socket at the other end of the *C2325* cable usually stays connected to the *MB2325* board.

3.14.2 Plugging MB2325 into the host computer

The *MB2325* serial communications board (Figure 2) has a 25 pin, female, type D-connector. On older computers, *COM1* is a 25pin male D-connector. Today's computers, however, possess a 9 pin connector or Universal Serial Bus (USB) connector. You will need a 9 to 25 pin converter (available at most computer and electronics stores) to enable connection between the host computer *COM* port and the *MB2325*. When the *MB2325* is plugged into the *COM1* port of the host computer and a terminal emulator program attached to *COM1* is open and connected, then the *LED D1* will light. If *LED D1* does not light, check your terminal emulator program to make sure it is associated and connected to *COM1*. If it is and D1 still does not light, then the serial port of the host computer may be disabled or used by another application. In either case, the computer will be unable to communicate with the robot.

3.14.3 Connecting the Host computer to TALRIK-IV™

After connecting the *MB2325* to the computer, take the 6-wire *C2325* cable and insert either end onto J2 of the *MB2325*. Connect the 6-pin socket at the other end of the *C2325* cable to the 6-wire pig-tail cable with a male connector at its open end, making sure to connect pin-1 to pin-1 at each end. On the *MB2325* and *MEKAVR128*™ boards, pin-1 is the leftmost pin of the 6-pin male header. The 6-pin socket end of the pig-tail inserts into the 6-pin male header USART0/PROG on the *MEKAVR128*™ board. Connect the 6-pin male header at the end of the pig-tail to the socket at the other end of the *C2325* cable coming from the *MB2325*. When you turn power on to the robot, *LED D2* should shine. Both LEDs shining indicates an established serial link. *LED D1* shining indicates connection to the host computer and *LED D2* shining indicates connection to the robot.

3.14.4 Minor Troubleshooting of Serial Connections

The lights on the *MB2325* let you know that the basic connections are working. If on power up of the robot, *LED D2* does not light, the *C2325* cable may not be connected properly or the batteries may not be charged. Reverse the *C2325* cable to see if the light comes on. If the batteries are charged, check battery and power connections to the circuit boards. Particularly, check underneath the robot to verify the battery cable has not come undone.

If *LED D1* on the *MB2325* board does not function as specified, check that your terminal emulator program on the host computer is both executing and connected to the correct host computer's serial port. If this is not the problem, check to make sure no other program or device is using the host computer's serial port and, thus, is blocking your terminal emulator program's access to the port.

3.15 Where is TALRIK-IV™during Program Development?

The user will spend considerable time developing and testing programs to run on *TALRIK-IV™*. During the initial phases of this process the user will undoubtedly make many changes and run many variations of the programs. This procedure can be expedited by mounting *TALRIK-IV™* on a test platform that elevates the drive wheels off the floor or desk top so that the wheels turn freely without moving the robot. To prolong battery pack life during these long development sessions, keep *TALRIK-IV™* connected to the charger and the robot power switch off until ready to download or execute a program. Also, keep the serial communications cable to *TALRIK-IV™* connected to minimize plugging and unplugging it. When you are ready to test *TALRIK-IV™* on the floor, disconnect both the charger and the serial communications cable from *TALRIK-IV™*. If you work more than a few hours at a time, you will need back-up battery packs or a power supply of 7.5 volts rated at 3 amps, which you must configure with a 4-pin socket to fit the 4-pin BATT header on the *MEKAVR128™*.

3.16 Halting a Moving TALRIK-IV

Chasing down a moving *TALRIK-IV™*takes more skill than transporting it. A recommended procedure is to chase it from behind and turn the *POWER-SAVE/ON* mode switch to *POWER-SAVE.* or pick up the robot and turn it off, being careful to avoid the motors and sharp objects on the robot. The user can also program clever behaviors which halt the robot on certain conditions that can be artificially generated. For example, you can program the robot so that a touch of the rear bumper while the robot is going forward will stop it.

3.17 Runtime on a Full Charge

The length of time a *TALRIK-IV™* robot will run on fully charged batteries depends upon the robot program executing and how the robot reacts to its environment under the control of that program. The sample program `avoidtkavr.c`, for example, which moves the robot about an environment while avoiding collisions, runs about 1 hour on a full battery charge. The motors and the five IR range sensors run continuously during the hour. The five IR range sensors, collectively, consume more energy than the motors and place a significant drain on battery power.

3.18 Programming Time on a Full Charge

You will most likely spend considerable time developing and testing programs to run on *TALRIK-IV™*. To conserve batter power while programming, turn the robot power off and keep the robot on recharge. Of course, you must turn the robot power on when downloading and running programs, but do not remove the charger connection, unless you do a “floor” test of your program with robot wheels moving. Following this procedure will allow you to extend programming time on a single charge from 4 to 8 hours, depending on usage.

If you work more than a few hours at a time on programming, you will need back-up battery packs or a power supply adapter of 7.5 volts rated at 3 amps. The output of the adapter must interface with a 4-pin socket to fit the 4-pin BATT header on the *MEKAVR128™*.

3.19 Robot ASCII Command Interpreter (RASCI)

If you purchased the optional software package, *ROBOT ASCII COMMAND INTERPRETER* (*RASCI*) program (Mekatronix part number <RASCI_avr.zip>), along with infrared or radio interfaces for data transfer to and from the robot, you will be able to control the robot remotely from a host computer using *ASCII* command sequences. Further, *RASCI* provides functionality for uploading, to the host, robot sensor readings, robot data collection and the robot's general configuration or state and downloading commands, command sequences, and data to the robot from the host. *RASCI* allows you to connect the processing power of a host computer, either remotely (*IR* or wireless serial link), or locally (wired serial link with computer mounted on a modified bridge) to the mobility and data acquisition characteristics of a robot. For example, a video camera on the bridge of the robot transmits the image seen by the robot to a receiver attached to the host. Artificial Intelligence (*AI*) programs on the host processes the image and sends appropriate command responses to the robot for execution.

4. *TALRIK-IV™* SET-UP

If you are not familiar with *TALRIK-IV™*, we recommend you read *TALRIK-IV™* OVERVIEW, starting at page 11, before continuing.

4.1 TALRIK-IV™ Hardware Requirements

To create an operational robotic system you will need a few items in addition to the basic kit or assembled robot. Specifically, a complete robotic system requires the following hardware:

1. A completely assembled *TALRIK-IV™* robot,
2. A fully charged, 6-pack of AA, *NiCd* rechargeable batteries connected to the *MEKAVR128™* circuit board,
3. (Optional) Back-up 6-pack of AA, *NiCd* rechargeable batteries,
4. a) A host computer with an *RS2325 COM* port,
   or
   b) A host computer with *USB* and a *USB* to *RS2325* converter,
5. A Mekatronix *MB2325* communications board,
   a) A serial cable between the host computer *COM* port and the *MB2325* board,
   b) A 6-wire serial cable (*C2325*) from the *MB2325* board to the *USART0/PROG* header on the *MEKAVR128™* board,
   c) (Optional-Recommended) A pigtail connection between the *USART0/PROG* header on the *MEKAVR128™* board and the end socket of the *C2325*.

The batteries, *MB2325* communications board, *C2325* 6-wire serial cable, the serial cable between a *COM* port on the host computer and the *MB2325* board, and the host computer itself must be purchased separately. All components but the host computer may be purchased from a Mekatronix distributor.

4.2 TALRIK-IV™ Software Requirements

Mekatronix *TALRIK-IV™* Distribution Software consists of

1. *AVR Visual Studio™ 3.56* (Gratis),
2. *AVR_FREAKS* version of the GNU *C-Compiler*, `avr-gcc` (Gratis),
3. *TALRIK-IV™* library functions, include files, and test programs.

This Mekatronix portion of the software is bundled with your purchase of the robot. Arrangements to download the distribution software, which includes both the freeware and Mekatronix software, must be made with the vendor. Such downloads take place online through the World Wide Web. For your convenience, you can also purchase a CD with the distribution software.

4.3 Integrated Development Environment and C-Compiler System Requirements

You can use any *WINDOWS 95/98/XP/ME/2000/NT* or *UNIX* based computer system to develop programs for the *TALRIK-IV™*. Mekatronix configures software development around the Integrated Development Environment (IDE) of *AVR Visual Studio™ 3.56* from *ATMEL™* (http://www.atmel.com), which operates on *WINDOWS 95/98/XP/ME/2000/NT*, and the *C-Compiler* avr-gcc, the *AVR_FREAKS* version of the *GNU C-Compiler* (http://www.avrfreaks.net/). The *TALRIK-IV™* distribution software includes the `avr-gcc` compiler and the *IDE* freeware without fee. Further details on the distribution software can be found in *Section* 5, *TALRIK-IV™* DISTRIBUTION SOFTWARE, page 28.

If you use a *UNIX* based system you will have to obtain a *UNIX* version of the *GNU* compiler. While *AVR Visual Studio™ 3.56* is not available for *UNIX* based systems, *UNIX IDE's* are available. This manual will discuss implementation on a *WINDOWS* environment, but *UNIX* users should be able to translate non-artifact information into the *UNIX* environment without too much difficulty.

4.4 C-Language and Integrated Development Environment Support

Mekatronix does not provide technical support for the *GNU* compiler and *ATMEL™ IDE AVR Visual Studio™ 3.56*. If you have issues with the *C-Compiler*, please seek remedy at http://www.avrfreaks.net/ or http://gcc.gnu.org/ . For problems with *AVR Visual Studio 3.5™* refer to http://www.atmel.com .

4.5 PROGO Language Support

PROGO™ is a simplified robot language for beginners defined on top of the C-Language to be easily read without much training. Advanced Middle School students have demonstrated a basic programming competency in *PROGO™* with as little as four hours of instruction and laboratory experience. I wrote *PROGO™* to enable inexperienced programmers the pleasure of immediate access to robot programming. The ease in learning *PROGO™* eliminates the prerequisite and daunting task of developing programming skills in a complex computer language with incomprehensible syntax, just to write simple robot programs.

Figure 5 presents a *PROGO™* program that moves the robot along the perimeter of a regular polygon. *PROGO*-Language key-words appear in boldface type. The only obvious C-Language construct is the include statement `#include <tkIVavr_progo.h>` at the beginning of the program. This statement defines *PROGO™* for the C-Preprocessor to convert the *PROGO™* code to C.

The **Dictionary** for this program defines integers *N*, the number of sides, and the side length *side* which serve as inputs to the program through the serial port. **START** requires a press of the back bumper before the program continues execution. This feature reduces the danger of the robot from moving off your lab bench before you unplug the serial and charge cables and place the robot on the floor. Most of the program consists of terminal IO using the commands

Clear_screen,
Display "....." on_screen, and
New_line.

The quoted text between **Display** and **on_screen** is output to the terminal screen whereas **New_line** performs a carriage-return-linefeed cursor operation. The **Do_forever** construct is important in robotic behavior programming where the robot normally executes behaviors without conceptual end. The other program actions, I hope, should be discernable without further explanation.

Mekatronix *PROGO™* product line includes

1. *PROGO™ Language Reference Manual*
2. *PROGO™ Applications Manual*
3. *PROGO™ Distribution Software*

Check with a Mekatronix distributor for availability.

4.6 PROGO™ as a Vehicle for Learning C Programming

For the expert programmer, *PROGO™* may be too cumbersome and too limited in scope. However, the easy to learn *PROGO™* does serve as fine vehicle for seamlessly learning *C* programming. Since *PROGO™* is defined on top of *C,* all *PROGO™* programs are, in fact, *C*-programs in disguise. The programmer can mix any legal *C*-Language statements and constructs into a *PROGO™* program without compilation error, provided of course *PROGO™* syntax is not violated in the process. Since novices can learn *PROGO™* quickly, the usual barrier to fun programming a Mekatronix robot, namely, *C* language syntax and semantics, is initially bypassed. Thus, after learning *PROGO™*, a novice programmer can learn and use new *C*-Language constructs, one at a time, within the surrounding *PROGO™* support structure, without losing programming momentum, and with high motivation intact.

An instructor also can introduce *C* programming constructs, one at a time, into a student's *PROGO™* programs, while preserving understood *PROGO™* components of the code. As each construct is introduced, applied and understood, the student learns to replace *PROGO™* constructs with more comprehensive and powerful *C* language constructs.

In other words, the novice programmer can continue successful robot programming without a complete knowledge of *C*, all the while increasing *C* competency on his own or under instruction.

```
#include <tkIVavr_progo.h>

  Dictionary
    angle,
    side,
    N
  ok

Function angle_side
  Function_begin
    Forward side inches
    Wait 1000 ms
    Turn_right angle degrees
    Wait 1000 ms
  Function_end

Program_begin

  Clear_screen

  Display "POLYGON DRAWER" on_screen
  New_line
  Display "Enter number of sides:  " on_screen
  Set N to input_number
  Display "Enter length of sides in inches:  " on_screen
  Set side to input_number
  Display "Disconnect your robot and place on floor." on_screen
  New_line
  Display "Robot traces polygon with press of rear bumper." on_screen
  New_line

  Set angle to 360/N ok

  Do_forever
    START ok

    Repeat N times
      angle_side call
    Repeat_end

  end_Do_forever

Program_end
```

Figure 5. This *PROGO* program, that commands the robot to trace out a polygon trajectory, illustrates the readability of the language. Check a Mekatronix distributor for pricing and further details on *PROGO*™.

5. *TALRIK-IV™* DISTRIBUTION SOFTWARE

In this section we will discuss the different components of the *TALRIK-IV™* distribution software. This software comes bundled with the purchase of a complete *TALRIK-IV™*, kit or preassembled. The *WINDOWS EXPLORER* snapshot (Figure 6) presents all the folders in the distribution. To reduce your software costs, Mekatronix provides, without charge, the freeware software in folders <avrgcc> and <Avr Studio>. We have configured the software in these two folders specifically for use with Mekatronix robots and do not include the entire downloads, which you can obtain from http://www.avrfreaks.net and http://www.atmel.com, respectively, if you so desire. Mekatronix robot application and support programs are stashed into folder <avr-Meka>.

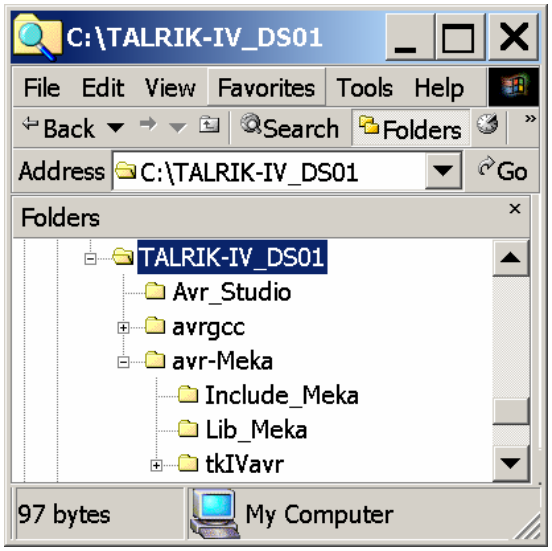


Figure 6. This snapshot of *TALRIK-IV™*distribution software illustrates all its folders.

The *Integrated Development Environment (IDE)* of *AVR Visual Studio™ 3.56* (Figure 7) from *ATMEL™* (http://www.atmel.com), which operates on WINDOWS 98/XP/ME/2000/NT, can be executed directly from the <Avr Studio> folder. Details on how to use this IDE is discussed in *Section* 7, Using AVR Visual Studio IDE. This software come with no warranty or support and is provided gratis for the convenience of Mekatronix clients.

Mekatronix uses the freeware *C-Compiler* <avr-gcc> in a subfolder of <avrgcc> , an *AVR_FREAKS* build (http://www.avrfreaks.net/) of the GNU (http://www.gnu.org) *C-Compiler*. This software come with no warranty or support and is provided gratis for the convenience of Mekatronix clients.

The *AVR_FREAKS* build of the *C-Compiler* depends upon specific directories or files, so do not rename or change the contents of any of the subfolders or files in folder <avrgcc>, unless, of course, you know how to do such things. Otherwise, you might confuse the linker and not be able to compile your programs.

WARNING! WARNING! WARNING!
DO NOT RENAME OR OTHERWISE CHANGE FOLDER <AVRGCC> OR ANY OF ITS CONTENTS.

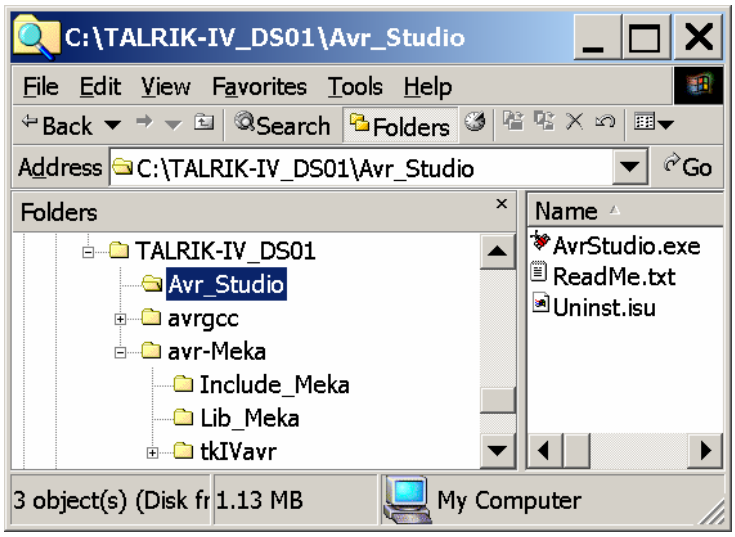


Figure 7. ATMEL's Avr Visual Studio™ executable program is stored in folder <Avr Studio>.

5.1 Brief Descriptions of TALRIK-IV™ Header Files

Read the *TALRIK-IV™* program header file listed in Figure 8 to obtain information on library functions and their usage.

The Linker finds the object files for header functions in library `libmeka.a` (Figure 9). Basic information about each header file follows.

5.1.1 analog.h

This header file references two functions which we have explained in *Section* 3.5, Program Access to Sensor Readings,

```
void analog_init(void);
int analog(unsigned char sensor_number);
```

The first function, `analog_init()`, initializes the analog-to-digital converter and must be executed before using the second function. Function `analog(sensor_number)` provides access to the current values of the specified sensor, $0 \leq$ `sensor_number` ≤ 28.

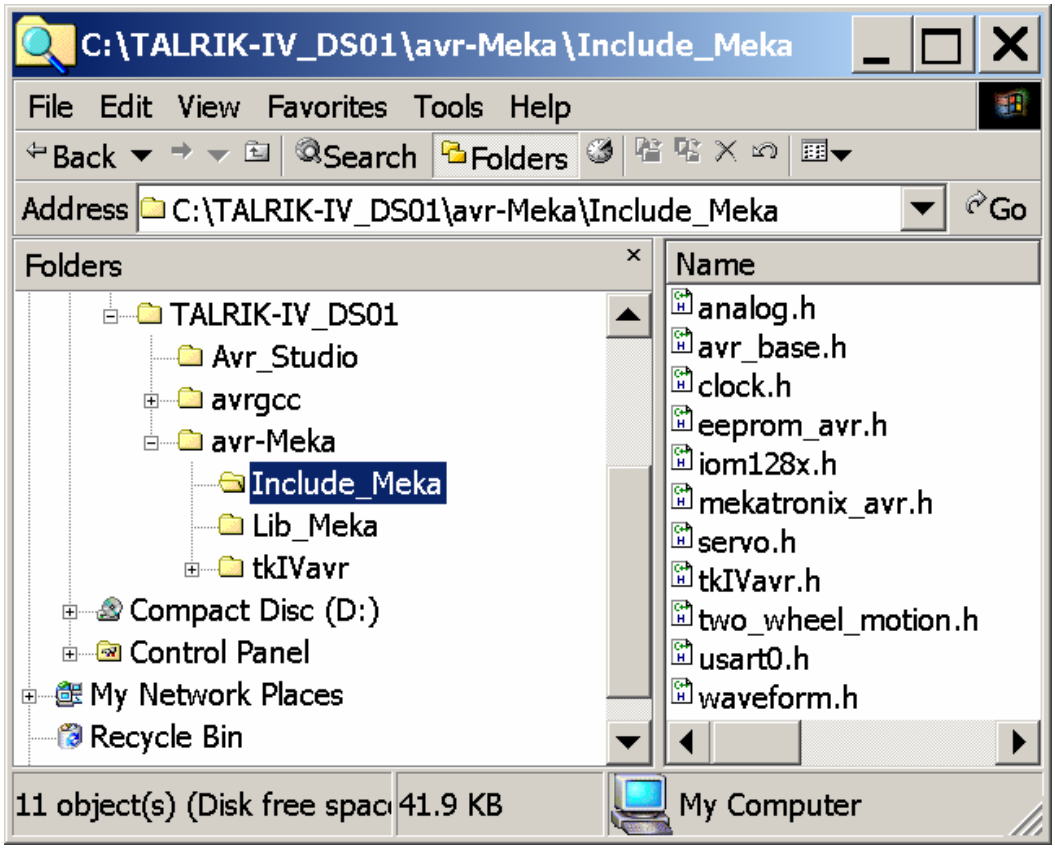


Figure 8. This WINDOWS snapshot lists all the *TALRIK-IV™* header files required to program the robot using Mekatronix library functions.

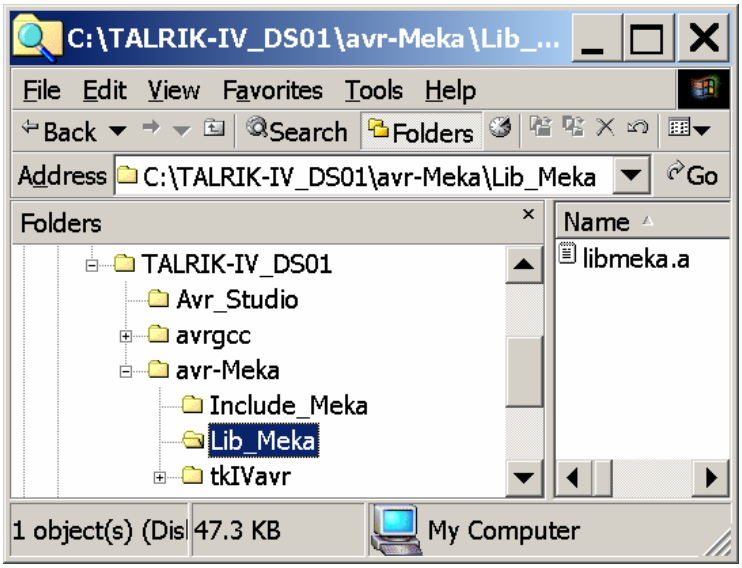


Figure 9. The object files for the Mekatronix library functions are archived in library file <`libmeka.a`> found in folder <`Lib_Meka`>.

5.1.2 clock.h

The clock functions

```
void clock_init(void);
void wait_ms(unsigned int n_msec);  // up to 65,537 milliseconds
void wait_sec(unsigned int n_sec);        // up to 59 seconds
void wait_minutes(unsigned int n_min);    // up to 59 minutes
void wait_hours(unsigned int n_hr); // up to 23 hours
void wait_days(unsigned int n_day);// up to 180 years in days!
```

allow you to program various delay times on the robot, from milliseconds to years. The global interrupt enable function `sei()` must be executed before `clock_init()`. The latter must be executed to enable any `wait_x()` function.

Global clock variables

```
volatile unsigned int msec, seconds, minutes, hours, days, timer_ms;
```

indicate the current values of the various software counters used to keep track of elapsed time since the previous `clock_init()`.

The global variable

```
volatile unsigned int elapse_ms;
```

acts as a software millisecond down-counter. The value of `elapse_ms` will decreases by one every millisecond after it has been set to a positive value. The count stops at 0 and remains there until reset by assigning `elapse_ms` a new positive value. Programs use `elapse_ms` to enable executing computations while the value of `elapse_ms` is not zero and then to cease such computations when the value becomes zero.

5.1.3 eeprom_avr.h

The *EEPROM* (Electrically Erasable Programmable Read Only Memory) in the MEKAVR128 is programmed with special functions,

```
unsigned char eeprom_read_byte(unsigned char *padr);
void eeprom_write_byte(unsigned char *padr, unsigned char data);
unsigned int eeprom_read_int(unsigned int *padr);
void eeprom_write_int(unsigned int *padr, unsigned int data);
unsigned long eeprom_read_long(unsigned long int *padr);
void eeprom_write_long(unsigned long int *padr, unsigned long int data);

void eeprom_write_servo_limits(void);
void eeprom_servo_limits_init(void);
```

The first six functions allow you to read `bytes`, `integers` or `long integers` from *EEPROM* or write `bytes`, `integers` or `long integers` to *EEPROM*. The remaining two functions transfer the values of the global variable `servo_limits[][]` to *EEPROM* global variable `eeprom_servo_limits[][]` or transfer `eeprom_servo_limits[][]` to `servo_limits[][]`.

EEPROM global variables

```
unsigned int eeprom_servo_limits[MAX_SERVO][2] __attribute__((section
                                                (".eeprom")));

unsigned int eeprom_servo_limits_indicator __attribute__((section
                                                (".eeprom")));
```

facilitate saving into *EEPROM* the servo upper and lower bounds (`servo_limits[][]`) for the specific servos on your robot. Since "standard" servos are not so standard in these limits, you can calibrate your servos once and save the calibrated values into *EEPROM* . The function

`eeprom_write_servo_limits()`

allows you to write the calibrated values into `eeprom_servo_limits[MAX_SERVO][2]`. The function `eeprom_write_int ()` permits you to assign the hex number `0xAAAA` to the *EEPROM* variable `eeprom_servo_limits_indicator`, which indicates the calibrated values in *EEPROM* will transfer to `servo_limits[][]` at initialization with `ROBOT_AND_SERIAL_INIT` or `ROBOT_INIT` macros. In this way, your robot-specific servo parameters stay with the robot, making possible servo code transference to other *TALRIK-IV™* robots without recompiling. Of course, the target robot must have its calibrated servo values in its *EEPROM* for this to work.

5.1.4 servo.h

The servo functions

```
// must execute sei() and then servo_init() before servo handler operates
void servo_init(void);

// general servo routine
void servo(unsigned char servo_number, unsigned int set_pulse_width);

// routine to drive hacked servos
void motor_hs(unsigned char index, int percent);
```

enable program control of motors and servos. As with other resources, the initialization functions `sei()` and `servo_init()` must be executed to enable the others.

The motor control parameters of `motor_hs(x,y)` specify a motor index `x = {0, 1}` and a percent of maximum motor speed

$-100 \leq y \leq 100$.

A negative percentage causes backward motion of the wheels and a plus percentage a forward motion of the wheels.

In actuality, the percent does not reflect a speed truly proportional to the maximum. The non-linear relationship between the speed parameter and actual speed may be determined experimentally. But, if your robot application program requires this information, you may not be approaching the problem from a robust point of view.

There are a number of parameters, constants and variables, too complicated to get into here, but one deserves consideration. The servo global variable

```
volatile unsigned int servo_limits[MAX_SERVO][2]=
      {
       {750,2975},{850,2625},{850,2625},{850,2625},{750,2975},{750,2975},
       {750,2975},{750,2975},{750,2975},{750,2975},{750,2975},{750,2975},
       {750,2975},{750,2975},{450,2675},{461,2686},
      };
```

indicates the nominal upper and lower setpoints for each servo (in microseconds). The defaults given here may not reflect the values for the servos on your robot. You will have to determine these limit values for the servos you attach to the robot, including the pan-head servo that comes with the kit.

5.1.5 usart0.h

Mekatronix offers a wide range of serial IO functions. To enable these functions your program must execute `usart0_init()`. The prefix `usart0_` indicates the ATmega128 microcontroller SCI interface used by the *MEKAVR128™*. Macros allow you to use the functions without this prefix. For example, the compiler will recognize both `usart0_getchar()` and `getchar()` as the same function. The functions `usart0_getch()` and `usart0_ungetch()` operate a *LIFO* (Last-In-First-Out) buffer on serial input so that a program examining an input string can back up to previous characters. Mekatronix does not implement the *stdio* function `printf()`.
Here is a list of the serial IO functions,

```
void usart0_init(void);
char usart0_getchar(void);
void usart0_putchar(char outchar);

char usart0_getch(void);
void usart0_ungetch(char c);

int usart0_putstr(char *buf, char stopchar);

int usart0_getstr(char *buf, char stopchar);
int usart0_getstring(char *buf, char stopchar, int max_length);

// get an integer
int usart0_getint(void);

// get a long integer
long usart0_getlong(void);
```

```
// put an integer
void usart0_putint(int n);

// put an unsigned integer
void usart0_putuint(unsigned int n);

// put a long integer
void usart0_putlong(long n);

// put a hex integer
void usart0_puthex(int n);

// put a hex byte integer
void usart0_puthex_byte(char n);

// put a binary integer
void usart0_putbin(int n);

// put a bin byte integer
void usart0_putbin_byte(char n);


/* string/integer conversions */

/*Convert string sp into an integer: *sxp index of last char,
 *    *valid = -1, not valid integer;
 *          *valid = -2, not valid integer and at end of string
 *          *valid =  1, valid integer
 *          *valid =  2, valid integer    and at end of string
 */
int atoi_meka(char *sp, int *sxp, char *valid);

// convert integers embedded in string sp into an array ip of integers
int atoi_array(char *sp, int *ip);

// simpler version of atoi_meka, convert ASCII into integer
int atoi(char *sp);

// convert integer n into string sp
int itoa_meka(int n, char *sp);

// Shorthand IO function names
#define getchar()       usart0_getchar()
#define getstr(x)       usart0_getstr((x), 0x1b)  //stop char is <esc>
#define getint()        usart0_getint()
#define getlong()       usart0_getlong()

#define putchar(x)      usart0_putchar((x))
#define putstr(x)       usart0_putstr((x),NULL)
#define putint(x)       usart0_putint((x))
#define putuint(x)      usart0_putuint((x))
#define putlong(x)      usart0_putlong((x))
#define puthex(x)       usart0_puthex((x))
#define puthex_byte(x)  usart0_puthex_byte((x))
#define putbin(x)       usart0_putbin((x))
```

```
#define putbin_byte(x)  usart0_putbin_byte((x))
```

5.1.6 waveform.h

The functions in this header file,

```
void waveform_init(void);
int waveform_frequency_change(long freq);
```

allow program control of square-wave signals of different frequencies on the FM headers FM1 to FM8. All FM signals must be the same frequency by hardware construction. The function `waveform_init()` initiates the generation of a default 40KHz square-wave on all of the FM header signal pins. To change the default frequency to any value between 16Hz and 4MHz use function `waveform_frequency_change(new_freq)`. The variable `new_freq` must be of type `long int`. The macros `WAVE_OFF`, `WAVE_ON` permit enabling or disabling square-wave generation on the FM headers.

5.1.7 mekatronix_avr.h: Mekatronix General Purpose Header File

All Mekatronix avr-robots use this header file. This header file contains the initialization macros `ROBOT_AND_SERIAL_INIT` and `ROBOT_INIT`. The serial functions `CLEAR_SCREEN` and `HOME_CURSOR` provide useful screen control for terminal emulator interaction.

```
#include <avr_base.h>
#include <analog.h>
#include <clock.h>
#include <eeprom_avr.h>
#include <servo.h>
#include <usart0.h>
#include <waveform.h>

#define CLEAR_SCREEN usart0_putstr("\x1b[2J\x00\x1b[2J\x00\x1b[2J\x00",NULL)
#define HOME_CURSOR  usart0_putstr("\x1b[1;1H",NULL)   //Home cursor
#define NSENSORS  29
```

5.1.8 avr_base.h

This header file uses the `avr-freaks` header files necessary for the `avr-gcc` compiler and linker. The exception is `<iom128x.h>` developed for Mekatronix code use.

```
#include <io.h>
#include <interrupt.h>
#include <sig-avr.h>
#include <iom128x.h>
```

5.1.9 tkIVavr.h: Required Header File in all TALRIK-IV™ Programs

This header file expresses the robot-specific *TALRIK-IV*™ macros and legacy functions of the earlier *TALRIK-II*™ and is the only header file that must be included in all *TALRIK-IV*™ programs. The includes of this header file are

```
#include <mekatronix_avr.h>
#include <two_wheel_motion.h>
```

The second one, among other things, provides some useful motor control macros for open-loop control of the robot motion,

```
#define Go              move(MAX_SPEED, MAX_SPEED, -1)
#define Stop            move(ZERO_SPEED, ZERO_SPEED, -1)
#define Halt            Stop;
#define Reverse         move(-MAX_SPEED, -MAX_SPEED, -1)
#define Spinccw         move(-MAX_SPEED, MAX_SPEED, -1)
#define Spincw          move(MAX_SPEED, -MAX_SPEED, -1)
```

5.2 Brief Descriptions of TALRIK-IV™ Code Files

Figure 10 illustrates the three programs distributed with the robot.

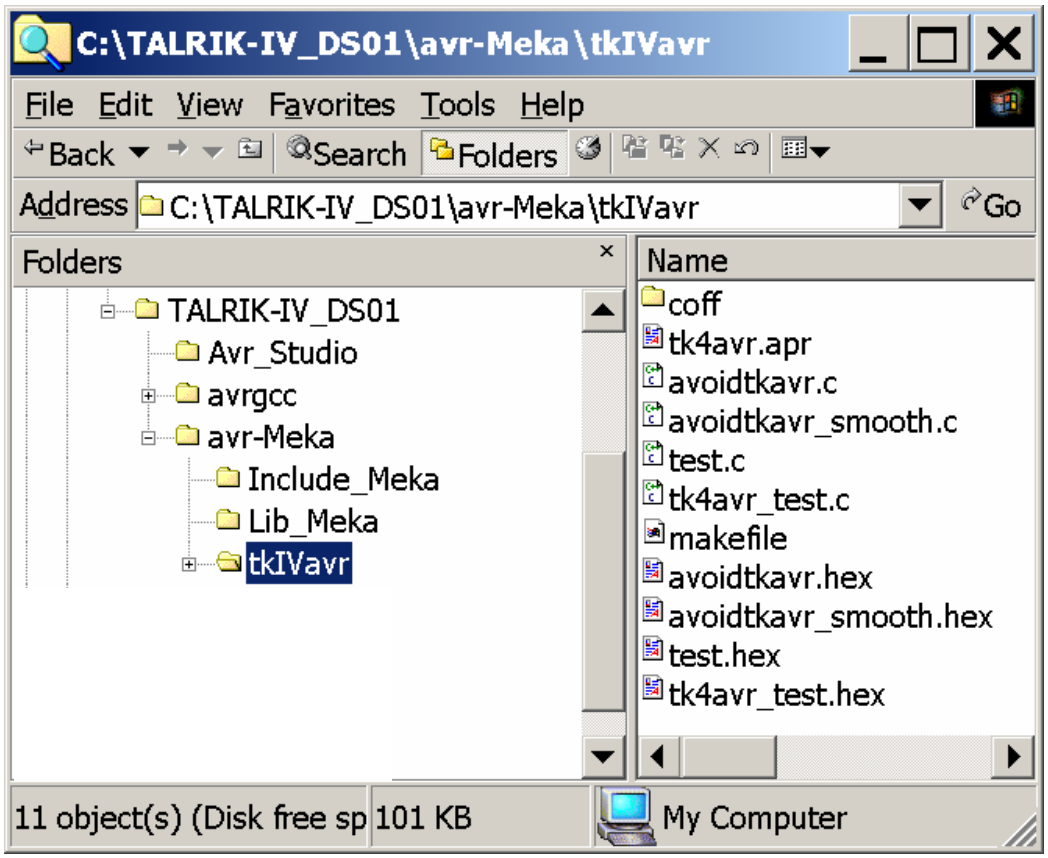


Figure 10. The code file folder <tkIVavr> contains a few useful programs and their compiled *hex* files which can be downloaded into the robot microcontroller and executed.

These programs, collectively, illustrate how to use or test most of the resources of the robot. The program `test.c` is the classical "Hello World" test program. A simple collision avoidance program `avoidtkavr.c` will read the front cross-eyed *IR* range sensors, and turn away from any obstacles in its path. Also, if something hits the bumper, the robot will backup, turn, and go on. To start this program executing, the back bumper must be pressed. This is a precautionary technique to prevent the robot from inadvertently driving off your workbench surface and is recommended for use by you as a robot coding practice. This version of the program induces sudden, jerky movement when the robot quickly changes direction to avoid an obstacle. A variation, `avoidtkavr_smooth.c`, executes smoother transitions between motor speeds as the robot avoids obstacles.

The program `tk4avr_test.c` allows you to test all the features of the *TALRIK-IV* microcontroller, *MEKAVR128*™ in the context of the robot. In order to run this program, the robot must communicate with the host computer running a terminal emulator. A physical, serial communication link must be present, e.g. the standard Mekatronix serial cable connection via the MB2325 board or optional infrared (*IR*) or radio frequency (*RF*) serial communication devices. For more details on the usage of this program refer to *Section* 10, TALRIK-IV™ Testing.

The serial protocol of the terminal emulator program must be

baud=115200, 8 data bits, 1 stop bit, no parity, no flow control.

The screen configuration must have at least 24 rows and 80 columns to display properly.

The program `tk4avr_test.c` offers nine test choices,

1. Test TALRIK IV Sensors: Refresh Data Continuously
2. Test TALRIK IV Sensors: Specify Refresh Delay Between Data Sets
3. Test TALRIK IV Sensors: Manual Refresh Control Between Data Sets
4. Test TALRIK IV Sensors: Average Samples During Refresh Delay
5. Test TALRIK IV Sensors: Average Over N Samples
6. Run TALRIK IV Motors (Caution! Wheels will turn immediately)
7. Test TALRIK-IV Servos and Motors
8. Test Digital Input-Output
9. Test FM Waveforms

The first five selections relate to sampling the 29 analog sensor channels in different ways. Test 6 runs the motors through their speed ranges, so be sure the robot wheels are elevated off the desk top when executing this test. Test 7 allows you to individually control and test any servo or motor that you connect to the robot, up to 16 total, including hacked servos, such as the wheel motors.

Test 8 allows you to manipulate and control the seven digital I0 ports (PORTA, PORTB, PORTC, PORTD, PORTE, PORTF, and PORTG) and their corresponding data direction registers (DDRA through DDRG) of the ATmega128 microcontroller. PORTA and PORTB have been assigned to the Servo Bus and are not available for Digital IO. The port pins available for digital IO on the *TALRIK-IV™* implementation are

1. PE2, PE3, PE5, PE6, PE7;
2. PB0, PB1, PB2, PB3, PB5, PB6, PB7;
3. PG3, PG4;
4. PORTD (PD0 to PD7)

Each of these port signal pins come out on 3-pin male headers consisting of *signal*, *power*, and *ground* connections.

You can download the hexadecimal object code for these three programs (extension ".hex") using Mekatronix boot program loader that comes embedded with the *MEKAVR128™* microcontroller. Directions on program downloading will discussed in *Section* 8, Downloading Code to the Robot.

6. INSTALLATION OF *TALRIK-IV™* DISTRIBUTION SOFTWARE

This installation includes the avr-freaks `avr-gcc` *C-Compiler*, *ATmel*'s *AVR Visual Studio™*, and the Mekatronix library, include, and code files discussed in *Section* 5, *TALRIK-IV™* DISTRIBUTION SOFTWARE.

Installation of *TALRIK-IV™* is simplicity itself. Just transfer the folder <`TALRIK-IV_DS01`> to your host computer root directory or folder. For example, on the host hard drive <`C:\`> ,
<`C:\TALRIK-IV_DS01`>.
For expository reasons, the rest of this manual will assume your distribution software is installed on the hard drive labeled <`C:\`>.

You can create considerable problems for yourself if you change the names of any folders or their placement on your hard drive. For the general user I recommend you stay with the standard setup described in this manual. Expert users, who have familiarity with `makefile` files and path specifications, can make modifications to the folder structure as desired. The level of detailed knowledge to do this is beyond the scope of this manual, however.

7. USING AVR VISUAL STUDIO IDE

The powerful Integrated Development Environment (*IDE*) offered by *ATmel's AVR Visual Studio™* allows you to edit, and build projects in a convenient *WINDOWS* setting. While this configuration does not provide most of the features of *AVR Visual Studio™*, it does provide sufficient capabilities for practical usage. The following exposition illustrates just those capabilities. A more advanced version freeware is being devised to use these facilities.

Sophisticated programmers who wish to update their *AVR-GNU* tools or obtain further information about recent advances should check http://www.avrfreaks.net/.

7.1 Opening an Existing, but Empty, Project File

Open project file `tk4avr.apr` (extension `.apr`) found in folder `<C:\TALRIK-IV_DS01\avr-Meka\tkIVavr>` (when understood by context, the path `< C:\TALRIK-IV_DS01\avr-Meka\tkIVavr>` to code files will not be specified explicitly from here on). Double click on the project file name to open it. You will get the window in Figure 11 of an empty project the first time you do this. Later this will not be the case. We wish to add a C-program file with extension "`.c`" to Source Files and a `makefile` file to Other Files both of which have no entries at this point.

The Target: Compile & Clean found in the Project: tk4avr.apr window in Figure 11 that execution of Build, selected from a right-click on Target: Compile & Clean, or a left-click on Project in the Menu Bar, will invoke the compiler and then delete all the non-object code files generated by the process. Some of these files may be useful for debugging and, in the initial stages of program development you may not want to delete those files. Select Target-Debug in the drop down window in the project window to change to Target: Debug. This will leave all the files created in the process in the same directory as the code. Refer to 7.5, Compiling a Program in Avr Visual Studio™ for further discussion of this topic.

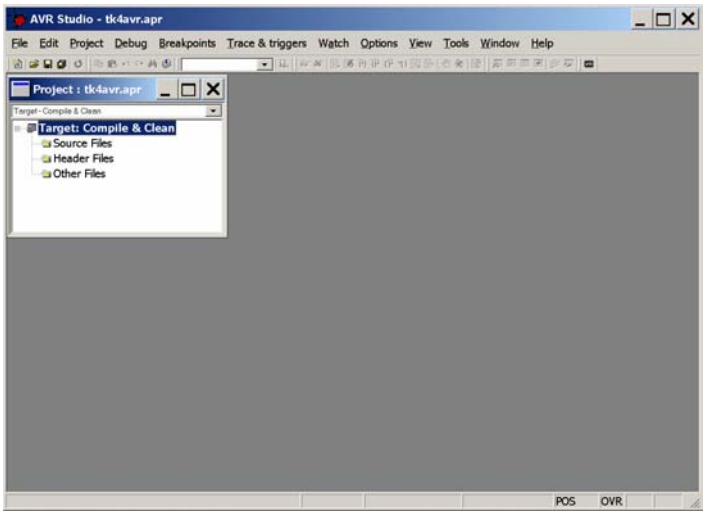


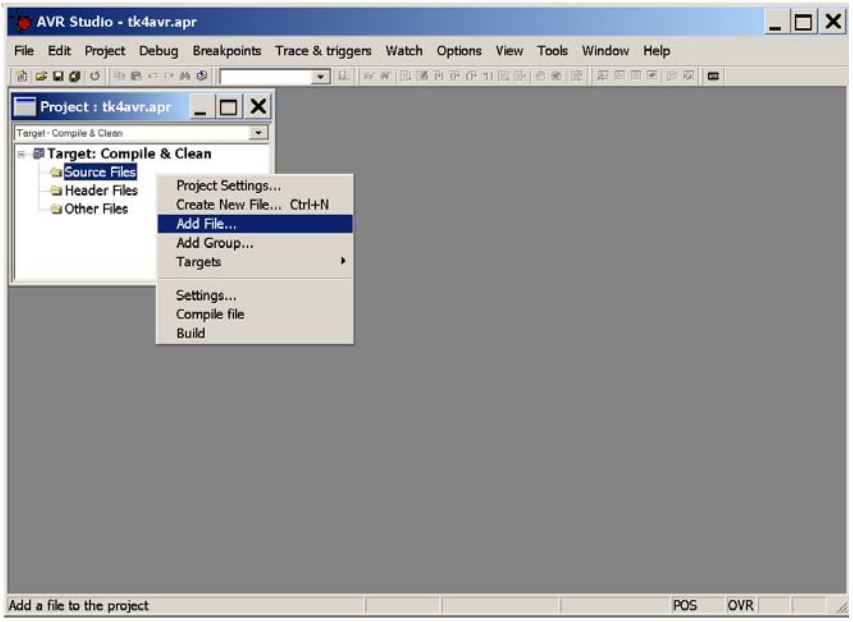
Figure 11. AVR Studio window for project file `tkavr.apr`, which is currently empty.

1. Select Source Files with the mouse, *right-click* to open selections, point mouse to Add File… (Figure 12a). If you are creating a new program, select Create New File…. Otherwise, browse, if necessary, to get folder `<tkIVavr>` and select program `test.c` (Figure 12b). The results appear in Figure 13. If you created `test.c`, it will be saved in the same folder as the project file, namely, `<tkIVavr>`.

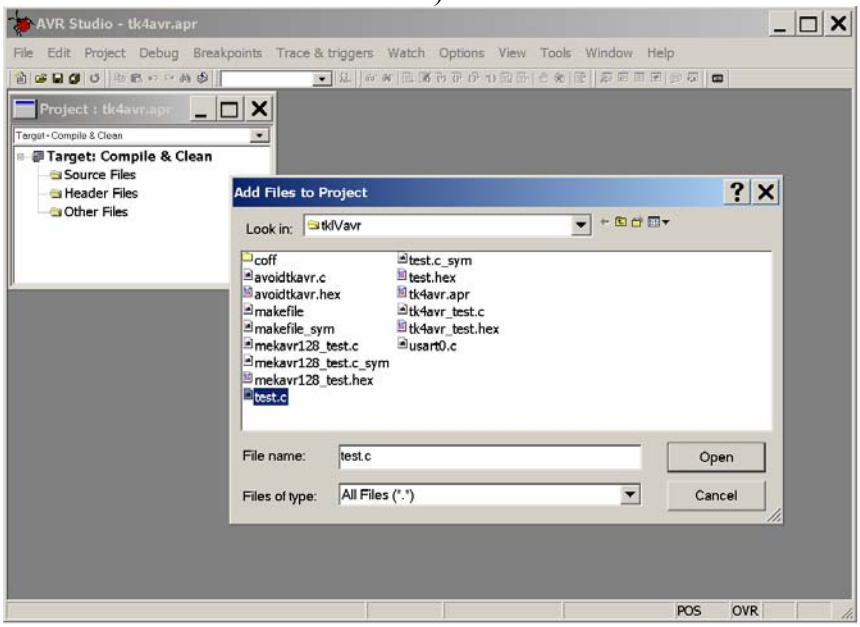
2. Select Other Files with the mouse, *right-click* to open selections, point mouse to Add File… Browse, if necessary, to get folder `<tkIVavr>` and select program `makefile`. This will add the file to the project (Figure 14).

IMPORTANT!

Make sure the `makefile` *selected is in the same folder as the code in* Source Files *that you wish to edit and compile.*



a)



b)

Figure 12. Add source file `test.c` to empty project `tkIVavr.apr`.

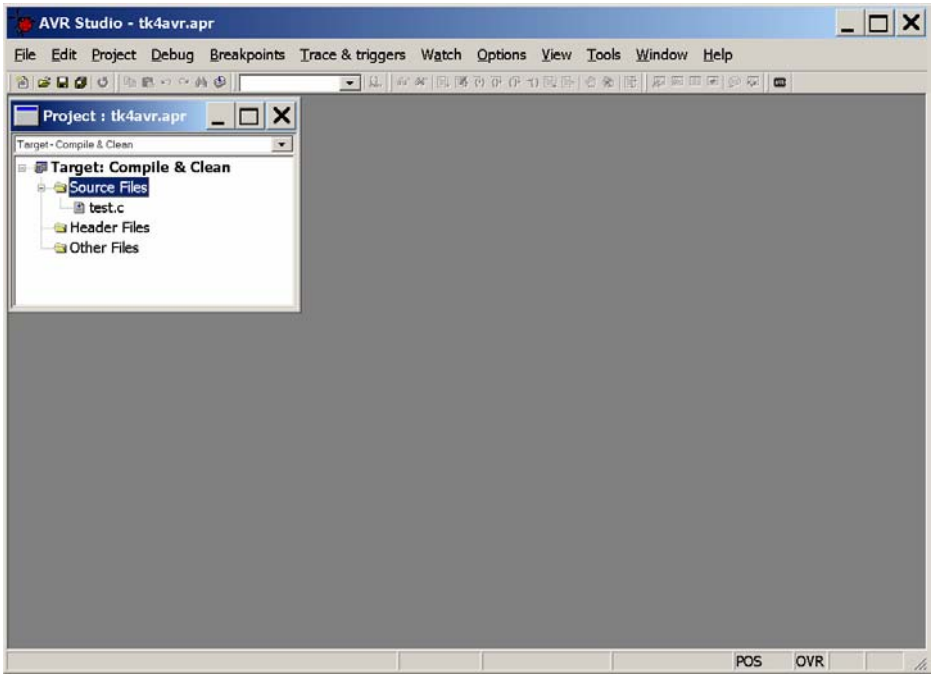


Figure 13. Project `tk4avr.apr` now has one source file `test.c`.

3. The `makefile` is extremely important to the compiler and linker and must have the specific structure provided. To see the contents double click on it. A window of the file will open up in the *AVR Visual Studio*™ window (Figure 15). The two landscape pages following displays the entire `makefile` with line numbers for easy reference. The # in the file indicates a comment line. The actual `makefile` actions occur in Lines 15, 18, 21 and 41, each of which I shall discuss.

Line 15 `TRG =`

"TRG = " specifies the name, WITHOUT the `.c` extension, of the target program to be compiled. In this case, the target program is `test.c`, so write `TRG = test` in the make file (Figure 16). You will need to change `TRG=` each time you change the target source program.

Line 18 `MEKA = c:\TALRIK-IV_DS01\avr-Meka`

Assigns the root directory for Mekatronix library (**Line 21**) and include files to the symbol `MEKA`. **DO NOT CHANGE THIS PATH, unless, of course, you have the expertise to do so!**

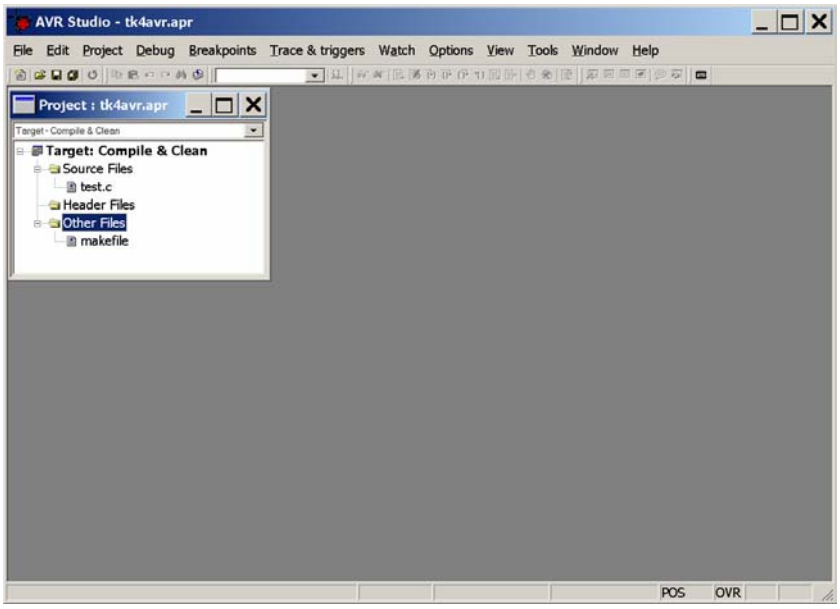


Figure 14. Add a `makefile` to the project `tkavr.apr`.

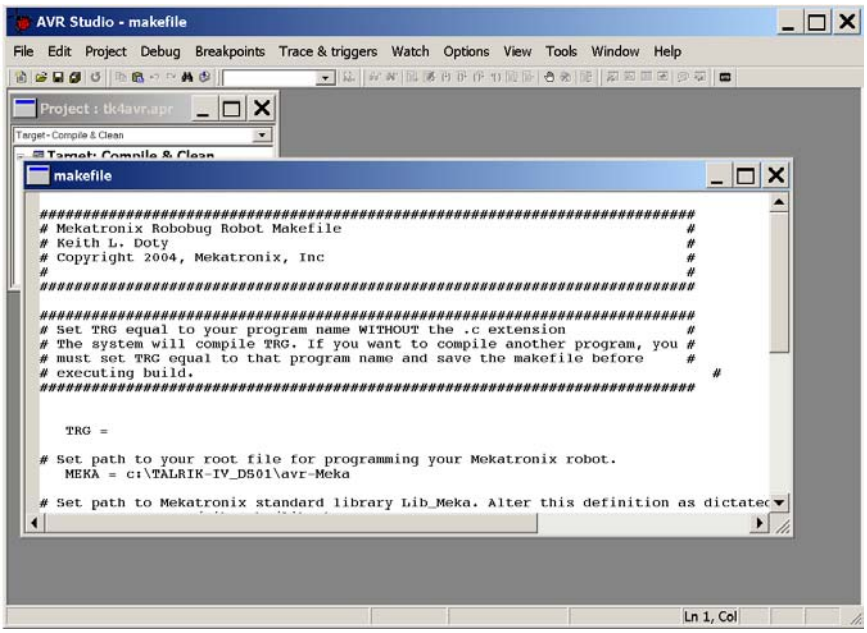
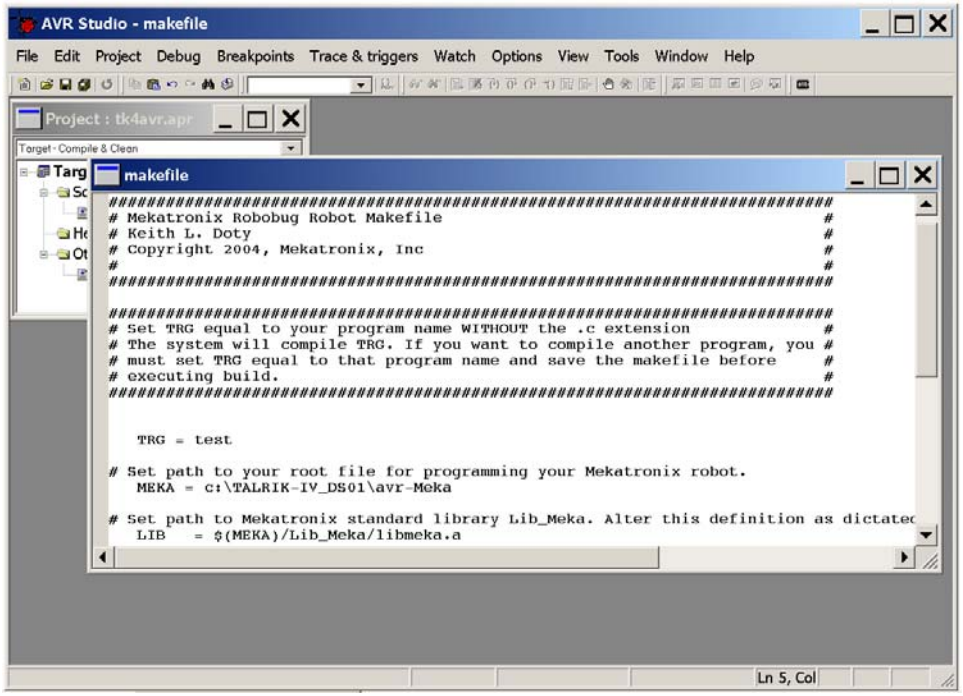


Figure 15. The `makefile` of project `tkavr.apr` must have a specific structure, part of which can be seen here.

```
1  ##############################################################################
2  # Mekatronix Robobug Robot Makefile                                          #
3  # Keith L. Doty                                                              #
4  # Copyright 2004, Mekatronix, Inc                                            #
5  #                                                                            #
6  ##############################################################################
7
8  ##############################################################################
9  # Set TRG equal to your program name WITHOUT the .c extension                #
10 # The system will compile TRG. If you want to compile another program, you   #
11 # must set TRG equal to that program name and save the makefile before       #
12 # executing build.                                                           #
13 ##############################################################################
14
15   TRG =
16
17 # Set path to your root file for programming your Mekatronix robot.
18   MEKA = c:\TALRIK-IV_DS01\avr-Meka
19
20 # Set path to Mekatronix standard library Lib_Meka. Alter this definition as dictated below.
21   LIB   = $(MEKA)/Lib_Meka/libmeka.a
22
23 ##############################################################################
24 # Mekatronix libraries you might need to specify with the standard library   #
25 # Lib_Meka. Depending upon your configuration, you will add one or more of   #
26 # the following to LIB:                                                      #
27 #   $(MEKA)/Lib_Bug/libbug.a        --Robobug                                #
28 #   $(MEKA)/Lib_Arm/libarm.a        --MekArm                                 #
29 #  $(MEKA)/Lib_Argos/libargos.a     --Argos Pan-Tilt Head                    #
30 #                                                                            #
31 # If you have all the above Mekatronix products then define LIB as follows:  #
32 #   LIB   = $(MEKA)/Lib_Meka/libmeka.a  $(MEKA)/Lib_Bug/libbug.a  $(MEKA)/Lib_Arm/libarm.a   $(MEKA)/Lib_Argos/libargos.a
33 ##############################################################################
```

```
34
35  ##############################################################################
36  # The make continues with meka_make.                                         #
37  # Typically, you will not need to change the include line below, nor         #
38  # change meka_make.                                                          #
39  ##############################################################################
40
41  include $(MEKA)/meka_make
42
```



43

44 **Figure 16. The makefile `make` is changed to reflect that the new target program is `test.c` by writing `TRG = test`. Important, the ".c" extension**
45 **must be omitted.**

Line 21 `LIB = $(MEKA)/Lib_Meka/libmeka.a`

You will not need to change this line to execute Mekatronix robot programs.

Line 41 `include $(MEKA)/meka_make`

This directive specifies that `makefile` continues with `meka_make` found in the folder `<c:\TALRIK-IV_DS01\avr-Meka>` specified by the string operation `$(MEKA)`. Discussion of `meka_make` is beyond the scope of this manual. **DO NOT CHANGE LINE 41.**

4. After changing `TRG =` to `TRG = test` on Line 18, save `makefile` and close it. Closing the file in the *Avr Visual Studio™* window does not delete it from the project. Although you can select any file in the project and delete it with the delete key on your keyboard, DO NOT DELETE the `makefile`, as you will need it each time you change `TRG =` to compile and link a different code file in `<tkIVavr>`.

At this point you are ready to open, edit, and compile `test.c`. Before doing this, however, I will show an easy way to create a new project from the distribution project `tk4avr.apr`.

7.2 Creating a New Project Folder and File

As you become more expert you may want to create more program folders with their own project files and multiple programs. When you do create a new program folder, say `<new_code>`, it must be in the root specified by

```
MEKA = c:\TALRIK-IV_DS01\avr-Meka
```

as is `<tkIVavr>`. Copy `makefile` from `<tkIVavr>` to the new directory `<new_code>`. All code files to be compiled in the new directory will use the same `makefile` file, except for Line 15 `TRG =`. That line must be reassigned to the name of the program to be compiled and `makefile` saved before compilation of the program. The detailed procedure is,

METHOD: Create New Project Folder and File

1. Create new folder, say `<new_code>` in `MEKA`.
2. Copy `tk4avr.apr` and `makefile` from `<tkIVavr>` into folder `<new_code>`.
3. If you have already started the program, say `new_test.c`, copy it to `<new_code>`, also.
4. Change the name of `tk4avr.apr` in `<new_code>` to new project name, `new_proj.apr`, say.
5. Open up file `new_proj.apr` and delete all files in the project (including `makefile` !)…these are the old `tk4avr.apr` project files.
6. From `<new_code>` Add (or create) `new_test.c` to the Source Files and Add `makefile` to Other Files. Be sure both of these files are selected from the `<new_code>` directory so that *Avr Visual Studio™* knows where to find them. Proceed normally with editing and compiling. Save your project before quitting. Next time you can just open the project and start right away.

There are more difficult ways to create a new project, but these are unnecessary to explain here.

7.3 Changing a Project's Target Code

You do not have to create a new folder and new project each time you want to develop a new program. The following shows how to write any number of programs using the same project name. For really complicated projects, or for a large number of programs that naturally should be collected into one folder, you may want to create a new project file and folder as described in *Section* 7.2.

Setting Up a New Target for a Project

1. Open the project and add new target to Source Files.
2. Delete the old target code in Source Files and all the other project files not used by the new target. Do not delete `makefile`.
3. Open `makefile`, change `TRG =` to the new target program name without the `.c` extension, and save `makefile`.
4. Add additional code files to the project needed by the new target.
5. Add any header files in folder Header Files, by right-clicking the mouse on the folder icon and selecting the appropriate action.
6. You are now ready to edit and compile the new target.

7.4 Editing a Program in Avr Visual Studio™

Open up a source file in Source Files for editing by double-clicking it. With the configuration shown in Figure 14 double-click on `test.c` to get Figure 17.

The *IDE* editor features typical program editor functions, some identical to those you find in any word processor and others specific to code generation. The best way to determine what these functions are is just explore the keyboard as you write a sample or test program. I do not suggest such explorations when you work with code you have concern about loosing. Once you familiarize yourself with the editor capabilities, you can begin editing programs in earnest.

Look at the distribution source programs to see example program layouts, layouts constructed for readability. Editor features allow you to auto-indent successive lines at the same lexical level (that is professor speak for auto tab setting!) to generate such layouts easily. When composing your own program, use a layout suitable to your tastes and style. Save your program frequently while editing. Do not forget to meaningfully comment your code to describe what the program does. Do this while you write the code! This is more important than you might think. You will especially appreciate the memory refresh comments provide when reading your program months later.

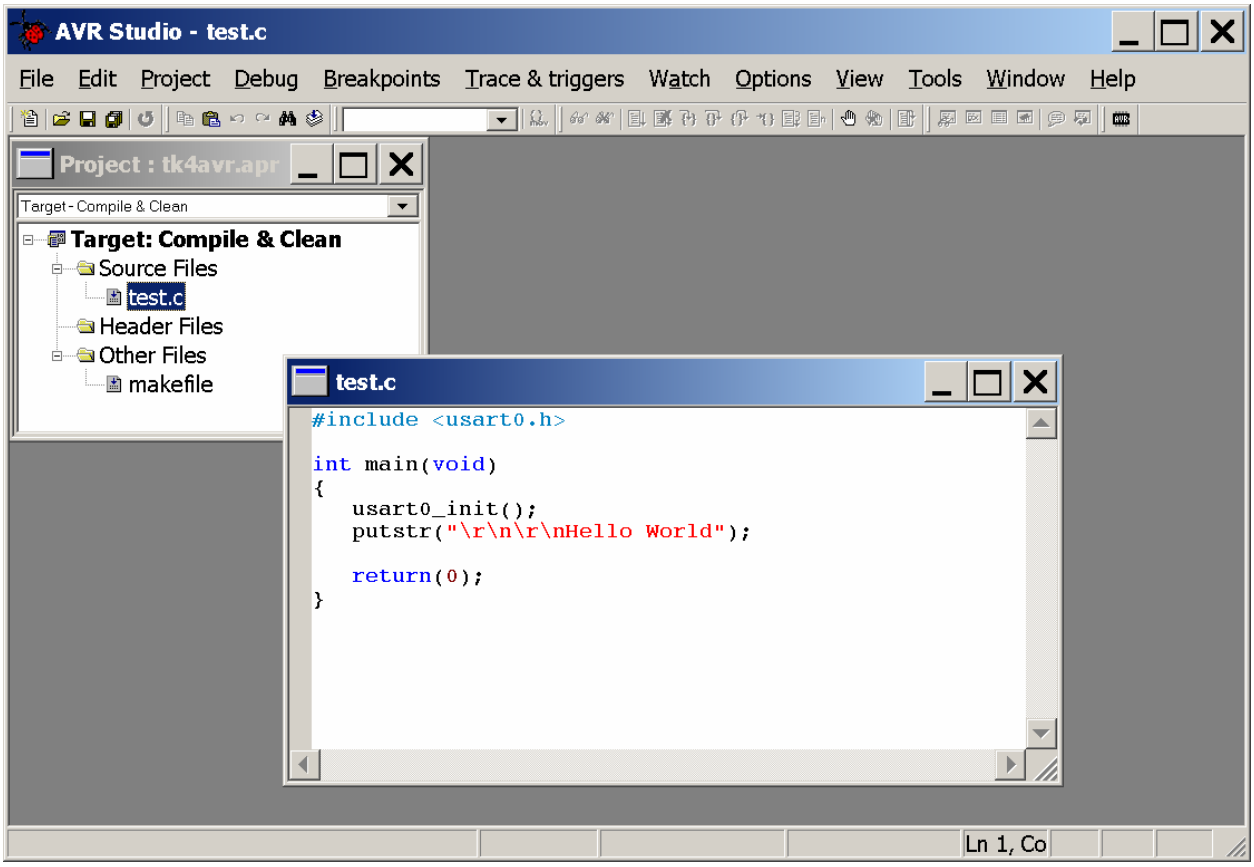


Figure 17. Open a source file for editing. The source code window `test.c` shows a complete, corrected program.

7.5 Compiling a Program in Avr Visual Studio™

After editing and saving your program edits in the *IDE* window to the point you want to attempt to compile your code, then select Project on the Menu Bar and then Build. *Visual Studio* will invoke `avr-gcc` *GNU C-compiler* to attempt to compile and link your project and provide error messages. You can do the same thing by right-clicking on Target: Compile & Clean and selecting Build.

Select Build for the correct version of `test.c` and you will get the results in Figure 18. The Project Output window displays, between the first "---begin---" and "---end---", the lines generated by the command line compilation of the program. The numbers under text, data, and bss indicate, respectively, the number of flash memory bytes, the number of *RAM* data bytes and the number of bytes for uninitialized global variables used by the program.

IMPORTANT! IMPORTANT! IMPORTANT!

If data exceeds about 4000 bytes of RAM, the program will compile, but not execute properly as the data requirements exceed the 4Kbyte capacity of the on-board RAM. Unfortunately, no error notice is given for this, so be alert and make sure data does not exceed about 4000bytes, especially when writing large programs.

The error indicator at the end of the first block, Errors: None, informs you as to the success of compilation. The second "---begin---/---end---" block performs the Clean process that removes all the generated files except the .hex object code.

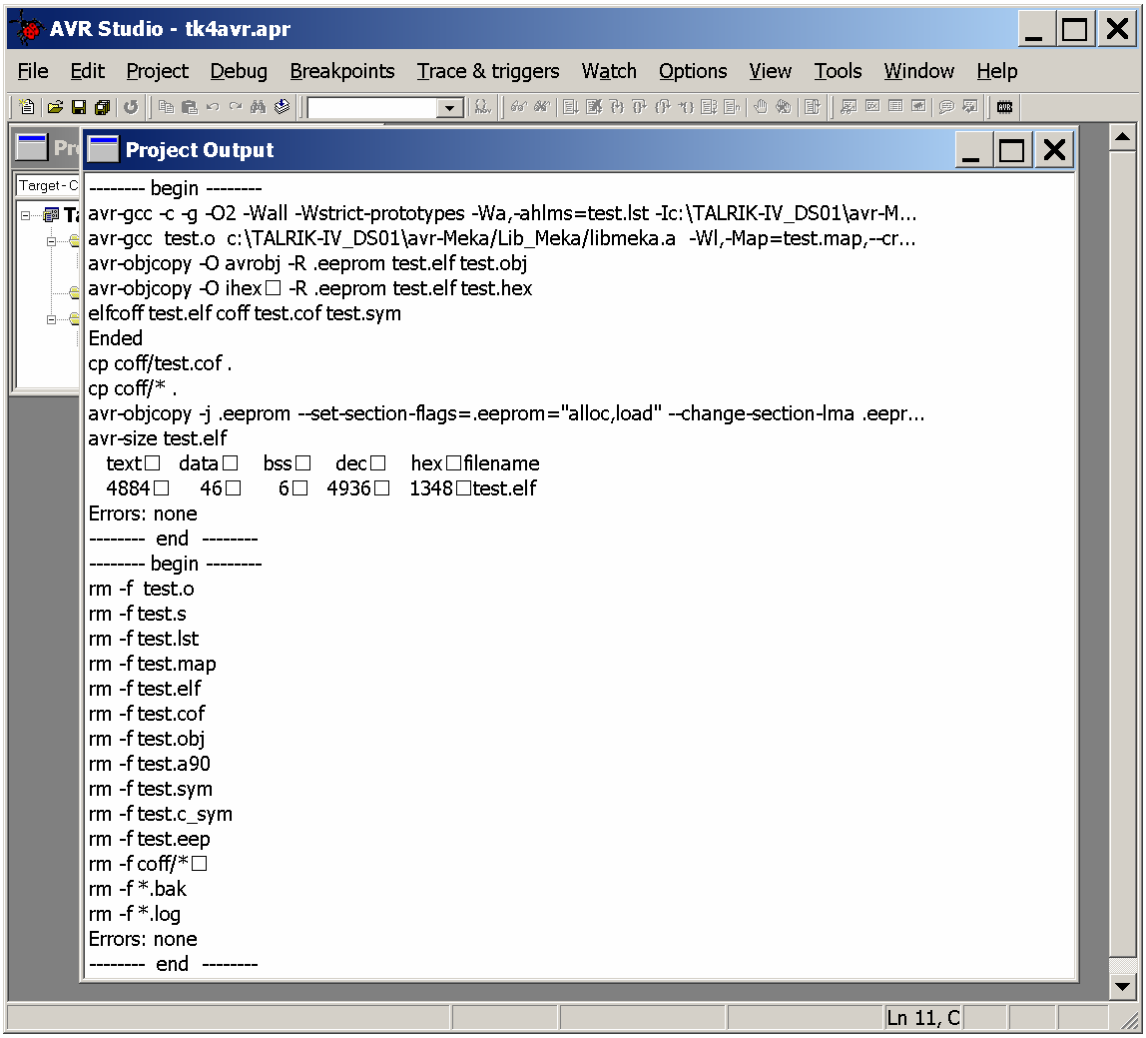


Figure 18. After invoking Build, the Project Output window appears on screen and shows the results of the Compile process, the first ---begin---, ---end--- block and the Clean process, the second ---begin---, ---end--- block. Without the Clean process, all the files removed (command rm) would still be in your code folder.

7.6 Debugging a Program in Avr Visual Studio™

The current freeware does not provide all the debugging helps such as Debug, Breakpoints, Trace & triggers, Watch, and many of the View options. You will have to debug from the error messages given by the compiler.

To illustrate debugging, refer to Figure 19. Attempt to compile the program `test.c` with several errors. The Program Output window displays the warning and error messages generated by the compilation process. These messages have the form <program>:<line_number>: <error_number>. Do not ignore warning messages. In fact, standard programming practices now insist on eliminating all warnings. We will do that here.

The first warning

test.c:2: warning: return type defaults to 'int'

indicates that the function name just scanned on previous line, namely, `main(void)`, must return an integer. To eliminate this warning, you must declare `int main(void)`. In fact, `'main'` must always be declared to return an integer. The next warning concerns the function `putstr("…")` found on line 3 of the function `'main'`,

test.c:3: warning: implicit declaration of function 'putstr'

To correct this is more difficult, unless you know that the function `putstr()` is declared in the header file `usart0.h` with object code in the Mekatronix library `libmeka.a` found in Lib_Meka. The correction is to add `#include <usart0.h>` above the `'main'` declaration.

The next warning,

test.c:5: warning: control reaches end of non-void function

actually couples to the first warning. Since `'main'` must return a value, there has to be a `return(<value>)` function somewhere in the code so that main will return the `<value>` specified. To correct this, insert `return(0)` in the line before `'}'`. Even though most of the time the return value of `'main'` is not used, to avoid this warning you must end `'main'` with `return(0)`. The second error on Line 5,

test.c:5:2: warning: no newline at end of file

may be somewhat obscure because the error is not visible. It just means that after the last line of your program you need a `newline` character. To correct this error, go to the end of the last line of

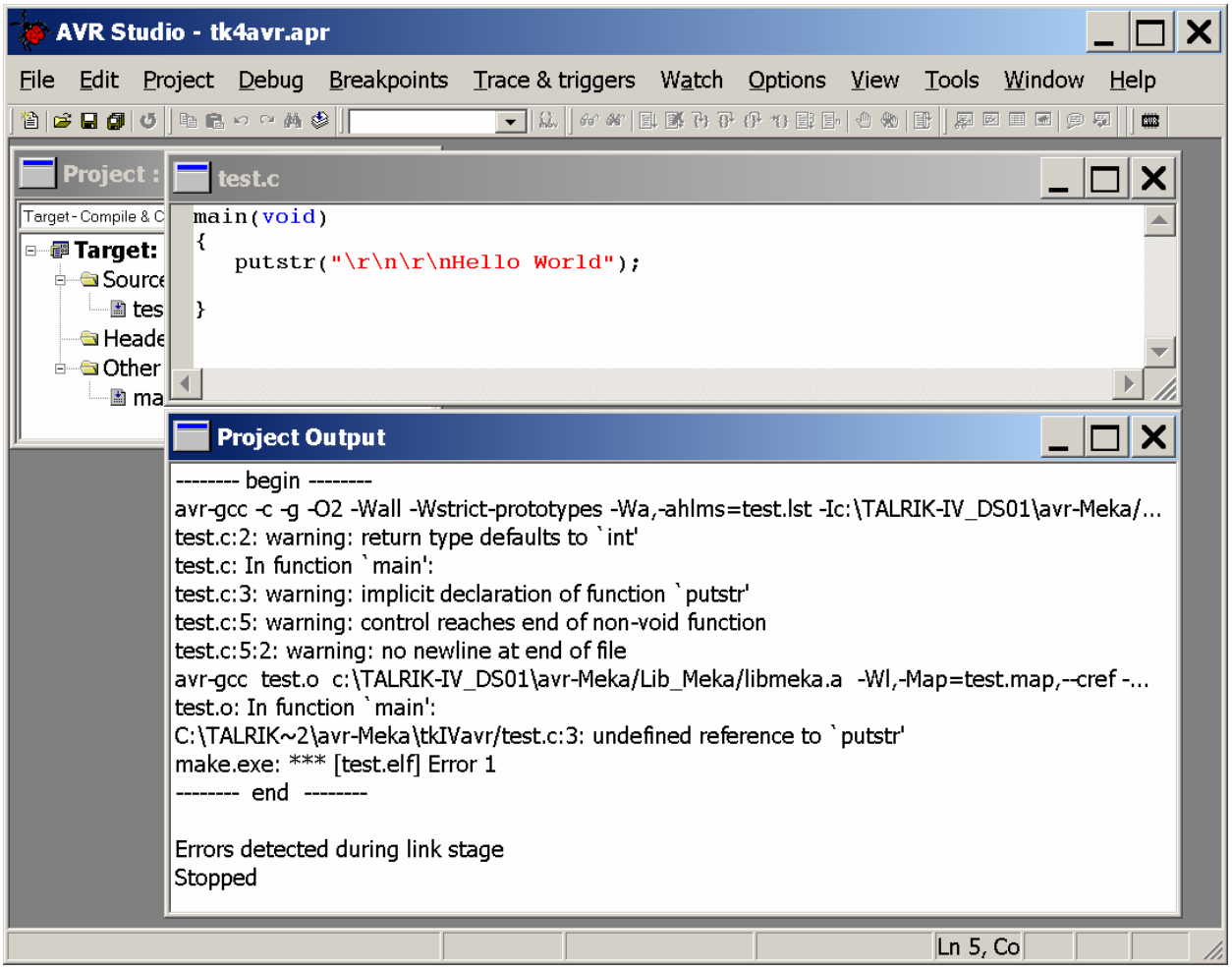


Figure 19. An attempted compilation of a version of `test.c` with several errors results in the error message display in the Project Output window.

the program and press the Enter key once to insert a final line that is blank. Multiple Enter keystrokes will also work, but this is not really necessary.

After you make all the corrections, your program should be *program-equivalent* (compiles to the same object code) to the program in Figure 17. The Project Output window should then look like that of Figure 18. If you compile the program under Target: Debug, you will get the Project Output window display in Figure 20. The files normally eliminated by Clean Process are highlighted in Figure 21.

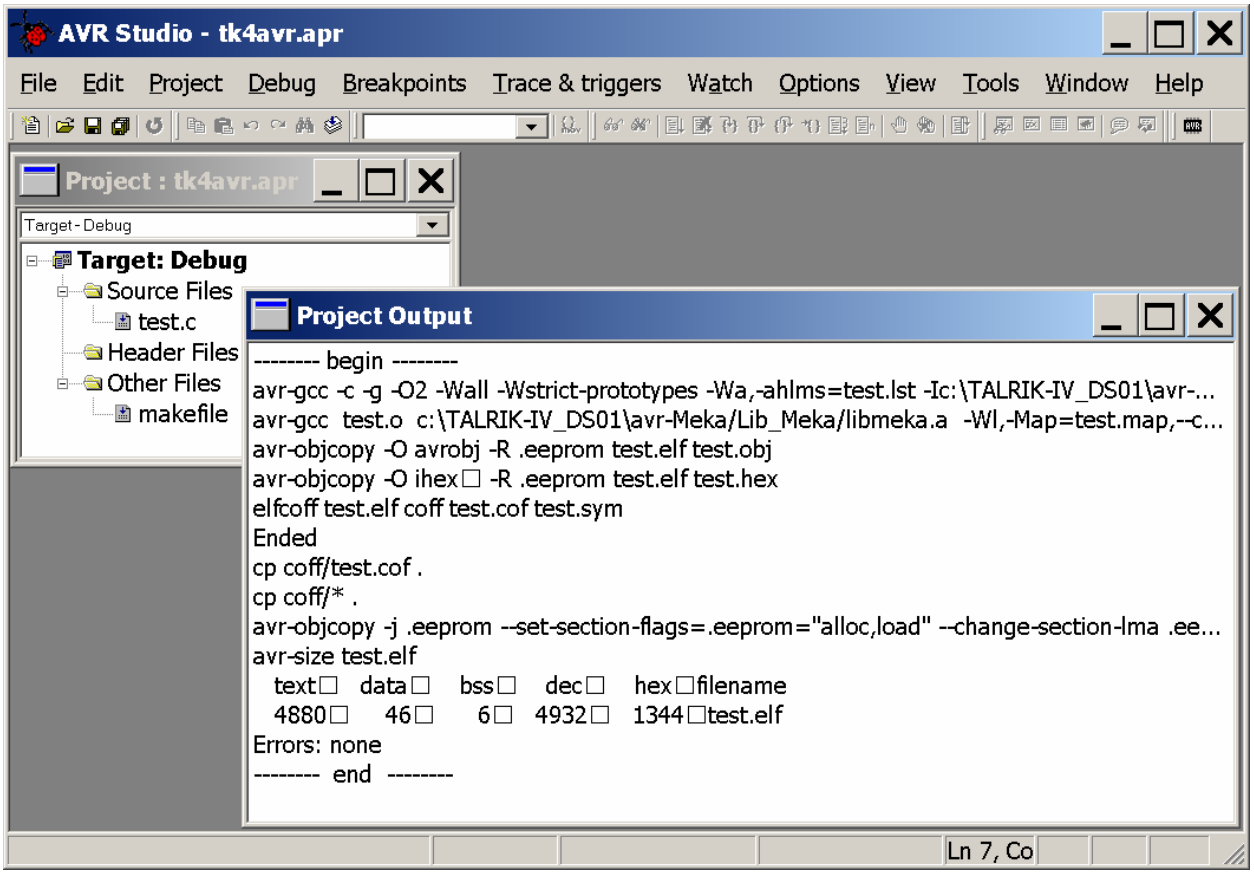


Figure 20. Compiling a program in Target: Debug will leave the temporary files in the project folder.

In general, when debugging a program, correct only the first few errors and obvious errors listed. Update (save) the corrected program file and recompile. Since many errors generate numerous, but spurious, secondary errors, efficient use of your time dictates this approach.

Once the program compiles, you may still have program logic bugs. The wide range of Mekatronix serial IO functions provide powerful tools for debugging program logic. Insertion of serial functions allow you to print current program variables at strategic points in the program on a terminal emulator screen and hold up continued execution until you press a character key. For example, the program segment,

```
…
putstr("\r\nInteger variable x = ");
putint(x);
c = getchar();
…
```

inserted into an appropriate location in the code, compiled, downloaded and executed successfully as part of the program would print the variable `x`, presumably yielding critical information to help you to debug a program logic error. The program stops at

```
c = getchar();
```

and waits for you to press a key on the keyboard before continuing execution.

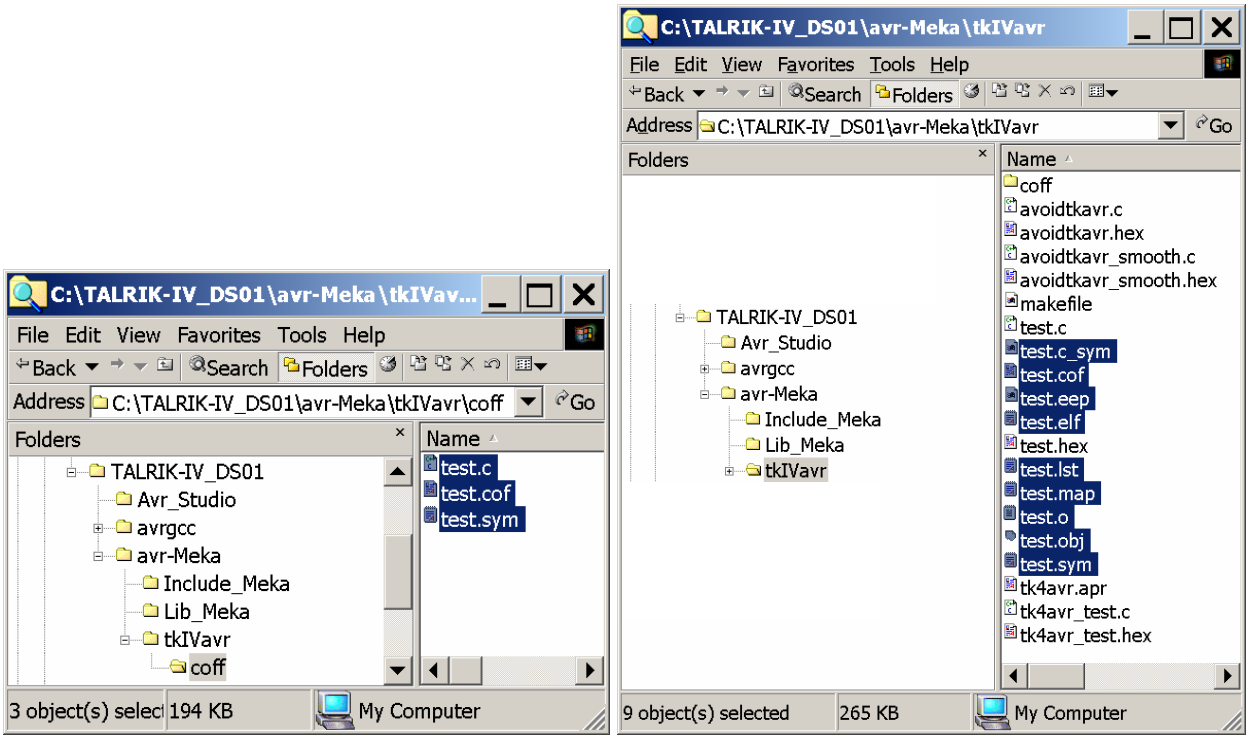


Figure 21. Files generated by the compiler that Clean process removes from the directories <coff> and <tkIVavr> are highlighted in the windows shown above.

8. DOWNLOADING CODE TO THE ROBOT

After successfully compiling a program you will want to download it to the robot to test and verify the principal components of its logic. Initial testing of your robot code may not actually involve running the robot on the floor, but, rather, will use the serial communication techniques described in *Section* 7.6, Debugging a Program in Avr Visual Studio™ for preliminary verification of program logic. Before executing the program, you must download it to the robot microcontroller *MEKAVR128*™ microcontroller.

8.1 X-Modem Download Procedure

The Mekatronix *MEKAVR128*™ robot microcontroller has a program downloader installed at manufacture into the 4Kbyte boot-loader section of the flash memory. If you use non-Mekatronix means for downloading code to the robot microcontroller, be careful not to erase the boot-loader.

To download code to the robot

1. Turn the robot power switch on and verify that the robot power indicator lights,
2. Switch the DOWNLOAD/RUN switch to DOWNLOAD position,
3. Connect the robot serially to a COM port on the host computer (Figure 3),
4. Execute a terminal emulator program on the host computer, say HyperTerminal,
5. Configure the terminal emulator as an ANSI terminal.
    a) The freeware version limits the screen size to 24 rows and 80 columns,
    b) Link emulator to COM port attached to the robot serial link,
    c) 115.2Kbaud, 8 Data Bits, No Parity, 1 Stop Bit, No Flow of Control
    d) ASCII setup: echo characters sent but do not send line ends with line feeds.

Set other terminal parameters to suit your own taste. Save your settings so you will not have to repeat this each time you invoke the terminal emulator.

With robot power on and the terminal emulator program executing, both *LEDs* on the *MB2325* communication board should light. Refer to *Section* 3.14, Serial Communication from Host Computer to Robot for more details.

6. Press the reset button on the robot. This is a check for proper operation.

You should see the character 'C' (capital c) appear on the screen. If this does not happen, make sure the terminal emulator is connected to communicate with the correct COM port. If this does not work, go over all serial connections and settings again to correct any possible errors. To be specific, the remainder of this procedure I will refer to HyperTerminal selections and responses.

7. Select Transfer on the *Menu Bar* and then Send,
8. In the pop-up window, select X-modem for Protocol: and then browse to find and select the hex file of interest, say `<filename.hex>`.
9. Select Send button at bottom of pop-up window,
10. Press the reset button on the robot, again.

This reset actually starts the downloading. You should see activity on the screen and blinking lights on the *MB2325* serial communications board.

11. If the download is successful, the terminal emulator screen will display,

```
Program Download Successful

Program Size in Bytes = <decimal>    <hexadecimal>
```

Where the program size, in bytes, is expressed both in decimal and hexadecimal.

12. To execute the downloaded program, switch the DOWNLOAD/RUN switch to RUN position and press reset again.

8.2 Download Summary

Assumptions: Correct serial connection, terminal emulator running with correct settings, batteries charged.

1. Turn on robot power,
2. Switch the DOWNLOAD/RUN switch to DOWNLOAD position,
3. In the terminal emulator, select Xmodem protocol transfer and browse to get the program hex object code `<filename.hex>`,
4. Select Send on terminal emulator,
5. Press reset switch on robot to start the Xmodem file transfer,
6. A message on the emulator screen alerts you to a successful or unsuccessful transfer.

8.3 Common Download Failure Modes

1. You selected the wrong extension for the program's object file, for example, `<filename.c>` instead of `<filename.hex>`,
2. You forgot to put the DOWNLOAD/RUN switch to DOWNLOAD position,
3. You did not select the Xmodem file transfer protocol,
4. You forgot to turn the robot power on,
5. The batteries are low,
6. The serial connection is not secure or properly made.

9. PROGRAM EXECUTION

The flash memory of the processor retains the program in memory, even with power off. Anytime after you successfully download a program to the robot, you can execute it, either then, or the next day, or next year…as long as you do not download another program in the meantime.

Procedure to Execute Program in Robot Flash Memory

1. Turn on power to the robot,
2. Switch the DOWNLOAD/RUN switch to RUN position,
3. Press reset.

The program now executes. Mekatronix robot programs that involve motion use the `START` macro command, which requires you to press the back bumper for the robot program to continue executing past the command. Thus, you can start your robot program, disconnect it and place it on the floor, and then press the back bumper to continue executing the programmed behavior. This is a safety precaution and recommended for your robot programs, too.

10. TALRIK-IV™ TESTING

Now that you can download programs into your TALRIK-IV™ robot, you will want to download the program `<tk4avr_test.hex>` to test and verify various robot features before writing behavior programs. In particular, you will want to test the sensors, motors and the pan-servo for correct operation and you may wish to characterize your sensors by measuring their responses to various stimuli.

The program `<tk4avr_test.hex>` serves as a useful hardware diagnostic as well. Whenever the robot appears to malfunction, or just simply when you want to verify all is in order, you can use this program to verify sensor, motor, and servo operation. Be aware, however, that what appears to be hardware failures or aberrant robot behaviors really amount to software errors or misconceptions about sensor capabilities or ill conceived behavior logic.

10.1 TALRIK-IV™ TEST PROGRAM

Assumptions: Correct serial connection, terminal emulator running with correct settings, batteries charged. HyperTerminal™ will be used to illustrate.

1. Download the program `<tk4avr_test.hex>` and execute it. How to do this is explained in *Section* 8, Downloading Code to the Robot and *Section* 9, Program Execution.
2. The terminal emulator screen displays a menu (Figure 22) from which you can select the test of interest.

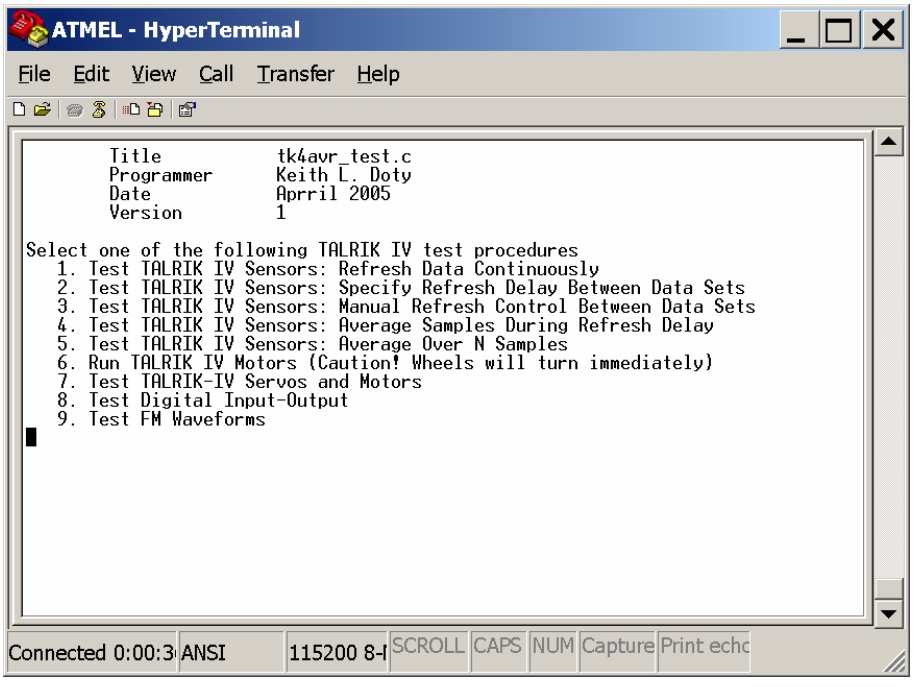


Figure 22. The main menu of `tk4avr_test.c` allows you to select one of nine robot tests.

The first five (*Test 1* through *Test 5*) of the nine test selections relate to sampling the 29 analog sensor channels in different ways. *Test 6* runs the motors through their speed ranges, so be sure the robot wheels are elevated off the desk top when executing this test. *Test 7* allows you to individually control and test any servo or motor that you connect to the robot, up to 16 total, including hacked servos, such as the wheel motors.

Test 8 allows you to manipulate and control the seven digital I0 ports (PORTA, PORTB, PORTC, PORTD, PORTE, PORTF, and PORTG) and their corresponding data direction registers (DDRA through DDRG) of the ATmega128 microcontroller. PORTA and PORTB have been assigned to the Servo Bus and are not available for Digital IO. The port pins available for digital IO on the *TALRIK-IV™* implementation are

5. PE2, PE3, PE5, PE6, PE7;
6. PB0, PB1, PB2, PB3, PB5, PB6, PB7;
7. PG3, PG4;
8. PORTD (PD0 to PD7)

Each of these port signal pins come out on 3-pin male headers consisting of *signal*, *power*, and *ground* connections.

10.2 TALRIK-IV™ Test Program Summary

The nine tests, in order, perform the following functions:

1. Outputs the sensors as fast as the program executes. Since the sensor data tends to vary from reading to reading, the data is often unstable and difficult to read.
2. Allows you to specify a fixed delay between each display of data to allow you to read these changes more easily, provided the delay is long enough.
3. Permits indefinite delays as it requires you to press any character key to refresh the sensor display.
4. Averages the data samples of a sensor over a fixed period of time. The number of samples taken during that period is also displayed.
5. Averages the sensor data over a fixed number of samples. This gives you an indication of how many samples you have to take of a specific sensor to stabilize the reading (a word of advice, do not write programs that rely on precise sensor readings, rather, use frequent sampling and decision making in its place).
6. Run the motors forward and backwards, repeatedly. Make sure the robot wheels do not contact any surface so they turn freely.
7. Allows manual control of servos and motors and to develop servo default limits. This test is described in further detail below.
8. Digital IO ports can be controlled individually with this test. Further description appears below.
9. The frequency of the square-wave generated on the FM header signal pins can be manipulated with this program. The frequency ranges from 16Hz to 4MHz. If you have

an oscilloscope attached to one of these pins, you can observe the square wave. At 16Hz you can attach a visible LED to an FM header and watch it.

10.3 Sensor Testing and Characterizing

A typical sensor display (*Test* 4) appears in Figure 23. The robot sensor names, listed in three columns, and their values, display in the upper part of the window. The standard *TALRIK-IV*™ kit sensors include only those highlighted in Table 2.

Table 2. Standard Kit Sensors Highlighted

Sensor Index	MEKAVR128 Header	SENSOR DESCRIPTION	PROGRAM ACCESS `analog(Sensor Index)` or Associated Program Defines
0	MUX16	Argos Left IR detector	`#define LIRA analog(0)`
1	MUX17	Left Eye Photoresistor (Argos)	`#define ECDSL analog(1)`
2	MUX18	Middle Eye Photoresistor (Argos Sonar)	`#define ECDSM analog(2)`
3	MUX19	Right Eye Photoresistor (Argos)	`#define ECDSR analog(3)`
4	MUX20	Argos-Head Right IR detector	`#define RIRA analog(4)`
5	MUX21	Left Nose Photoresistor (Line Follow)	`#define NCDSL analog(5)`
6	MUX22	Middle Nose Photoresistor (Line Follow)	`#define NCDSM analog(6)`
7	MUX23	Right Nose Photoresistor (Line Follow)	`#define NCDSR analog(7)`
8	MUX8	User Defined	`#define SENSOR8 analog(8)` `#define IR08 analog(8)`
9	MUX9	IR range sensor at 9 o'clock	`#define IRDL analog(9)` `#define IR09 analog(9)`
10	MUX10	IR range sensor at 10 o'clock	`#define IRDFL analog(10)` `#define IR10 analog(10)`
11	MUX11	User Defined	`#define SENSOR11 analog(11)` `#define IR11 analog(11)`
12	MUX12	IR range sensor at 12 o'clock	`#define IRDFM analog(12)` `#define IR12 analog(12)`
13	MUX13	User Defined	`#define SENSOR13 analog(13)` `#define IR01 analog(13)`
14	MUX14	IR range sensor at 2 o'clock	`#define IRDFR analog(14)` `#define IR02 analog(14)`

15	MUX15	IR range sensor at 3 o'clock	`#define IRDR analog(15)` `#define IR03 analog(15)`
16	ADC2	User Defined	`#define SENSOR16 analog(16)`
17	ADC3	User Defined	`#define SENSOR17 analog(17)`
18	ADC4	User Defined	`#define SENSOR18 analog(18)`
19	ADC5	User Defined	`#define SENSOR19 analog(19)`
20	ADC6	User Defined	`#define SENSOR20 analog(20)`
21	MUX0	Battery Level	`#define BATTERY analog(21)`
22	MUX1	Battery Charging	`#define CHARGE analog(22)`
23	MUX2	Rear bumper	`#define REAR_BUMP analog(23)`
24	MUX3	Front bumper	`#define FRONT_BUMP analog(24)`
25	MUX4	User Defined	`#define SENSOR25 analog(25)` `#define IR04 analog(25)`
26	MUX5	User Defined	`#define SENSOR26 analog(26)` `#define IR05 analog(26)`
27	MUX6	IR range sensor at 6 o'clock (Optional)	`#define IRDBM analog(27)` `#define IR06 analog(27)`
28	MUX7	User Defined	`#define SENSOR28 analog(28)` `#define IR07 analog(28)`

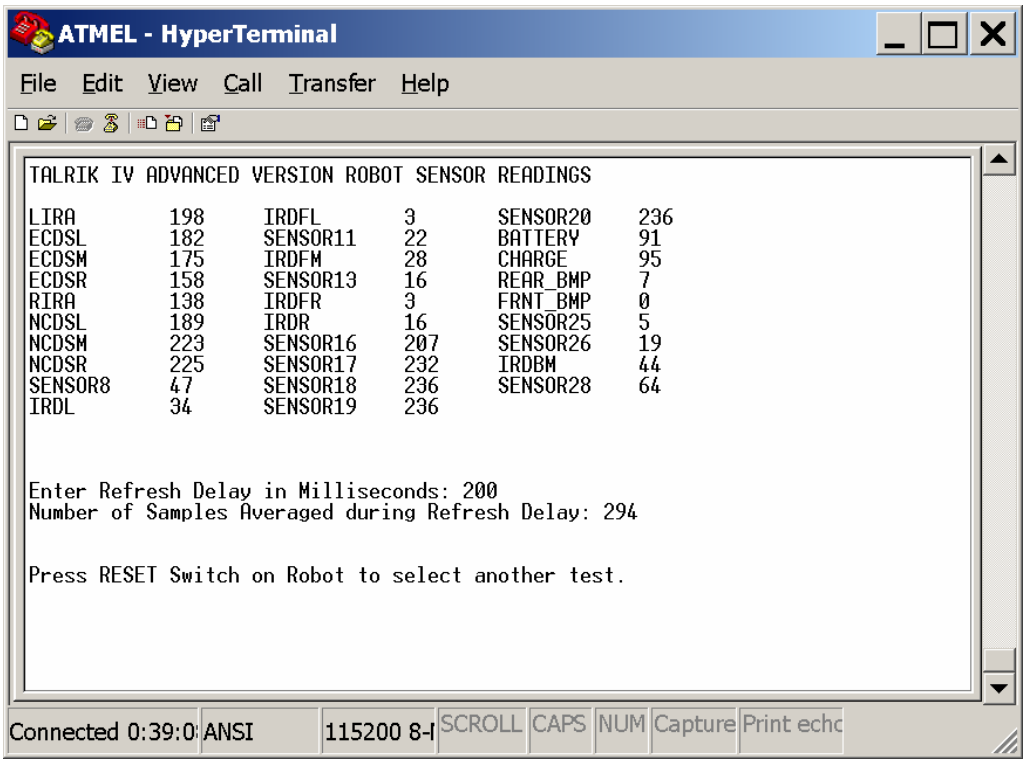


Figure 23. This window displays a snapshot of Test 4 with the refresh delay set at 200ms. Note the number of samples taken for each sensor during this time was 294. Depending on the program execution delay chosen, this number may vary by a small number.

At your leisure you can examine the sensor response to various stimuli and, if you have a spread sheet program available, enter the data and plot the sensor response versus distance or intensity of the stimuli or some other parameter of interest. For example, you can plot the IR range detector response to a white obstacle (say, a sheet of paper) versus distance. You will find the plot is highly non-linear and useful to know when programming robot behaviors.

You should characterize all the sensors on your robots with plots obtained in this manner. You might want to save selected sensor values in EEPROM to fully characterize your robot. A way to do this for servo limit checks is illustrated in *Section* 10.6, Servo Calibration.

10.4 Quick Verification of TALRIK-IV™ Sensor Operation

Depending on what information you want to gain, your test procedures will vary. If you just want to check to make sure the sensors respond to stimuli, but the exact values are not of interest, then a quick verification is all that is needed. This approach checks for major failures in the hardware.

Assumptions: Correct serial connection, terminal emulator running with correct settings, batteries charge, robot loaded with `tk4avr_test.hex`*, program is executing and the menu selection display in Figure 22 appears on your terminal emulator screen.*

Select *Test 3* Figure 22 to manually control the sensor sample refresh rate.

IR Detectors (IRDL, IRDFL, IRDM, IRDFR, IRDR)

1. Place your hand about *10* inches away from an IR range detector.
2. Hold your hand steady and press a key on the host computer keyboard with the other.
3. Read the sensor value.
4. Repeat *Steps 1* to *4* with your hand at various distances from the sensor.
5. Repeat *Steps 1* to *5* for a different sensor.

For more thorough testing, use white and then black construction paper at various distances. Record and plot the results.

WARNING! WARNING! WARNING!

The IR range detector outputs increase as an object approaches the detector, ***UNTIL*** *the object is about 3 to 4 inches away, at which point the output starts* ***DECREASING****. This characteristic of the IR sensors must be compensated for in collision avoidance and other range dependent behavior.*

Photoresistors (ECDSL, ECDSM, ECDSR, NCDSL, NCDSM, NCDSR)

1. Place your finger over the opening of a photoresistor to shut out the light.
2. Hold your finger steady and press a key with a finger on your other hand.
3. Read the sensor value.
4. Repeat *Steps 1* to *4* with your hand at various distances from the sensor opening.
5. Repeat *Steps 1* to *5* for a different sensor.

To more accurately record upper and lower limit values, use black construction paper or black ABS plastic (for example, a pen) to block the light to a photoresistor to get a "dark" reading. Saturate the opening of the photoresistor with a bright light to get a "light saturated" reading.

Bumpers (FRONT_BMP: 5 switches; REAR_BMP: 5 switches)

1. With a finger, push the bumper at a spot over a switch.
2. Hold your finger steady and press a key with a finger on your other hand.
3. Read the bumper sensor value.
4. Repeat *Steps 1* to *5* for a different bumper switch.
5. Now press multiple bumper switches and read their values.

You should get different readings on the bumper sensor for any combination of simultaneous bumper switch closures.

Charger

1. Plug the charger into the robot.
2. Press a key.
3. Read the Charge value.
4. Unplug the charger.
5. Press a key.
6. Read the Charge value.

With these values you can tell whether the robot is plugged into a charger or not.

Battery

1. Press a key.
2. Read the Battery value.

10.5 Servo and Motor Test

If you want to perform a quick check on the wheel motors, select *Test 6*, Figure 22. Be sure the wheels do not touch any surface as they move immediately!

For more complete control select *Test 7*. The servo and motor test, *Test 7*, allows you to interactively control any motor or sensor attached to the robot (Figure 24). Refer to highlighted items in Table 3 for a description of the servo assignments for the standard *TALRIK-IV™* kit.

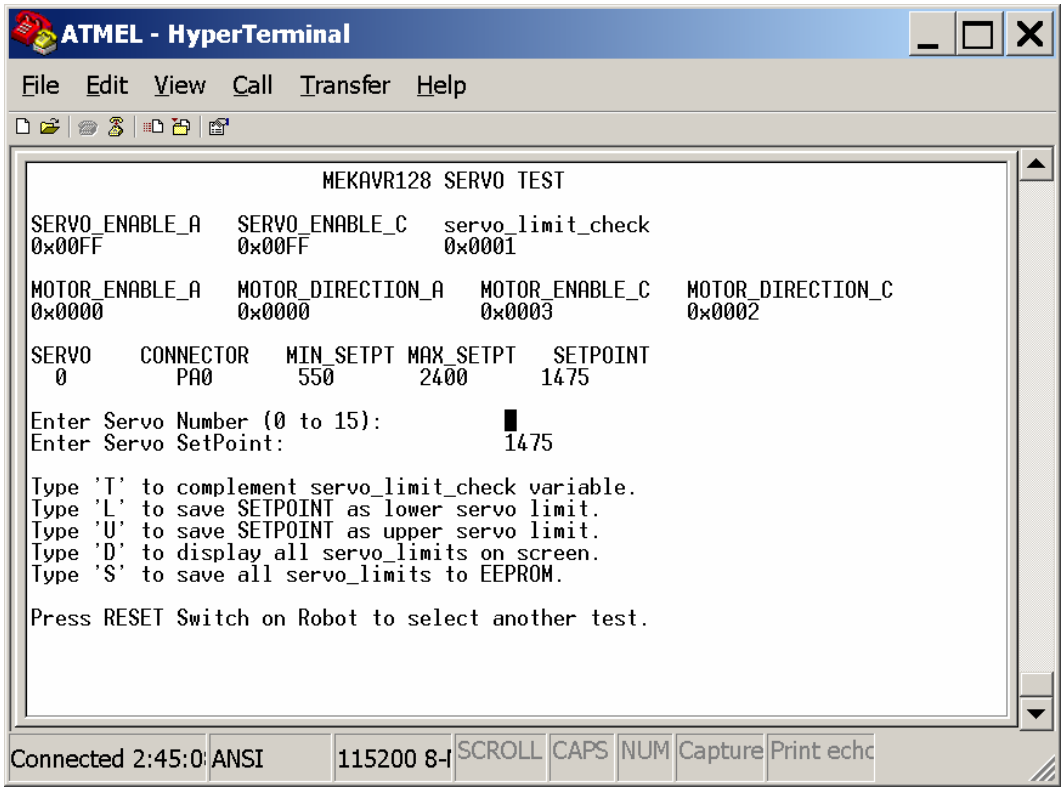


Figure 24. The servo test allows you to specify a setpoint for any one of a possible 16 servos attached to the *MEKAVR128*™ servo bus. In this window, servo 0, the pan-servo on top of the bridge, has been set at 1475 steps. This setpoint faces the sensor head directly forward for the servo used.

To move a servo, first enter the servo number, a number between 0 and 15, and then the setpoint, a number between MIN_SETPT and MAX_SETPT. After entering 0 for the servo number and 1000 for the setpoint, the 8th line down in the window will display servo-zero data,

SERVO	CONNECTOR	MIN_SETPT	MAX_SETPT	SETPOINT
0	PAO	550	2400	1000

This line indicates that you can select any number in the closed range of 550 to 2400 steps. If you enter any number not in the range, the robot will substitute the closest limit value, provided the control variable `servo_limit_check` equals *1*. More on this later. If you choose another servo number, it is likely that you will not know or remember the minimum and maximum setpoints for the servo you wish to control. To display them, just type the servo number and *0*. The servo will not move for a *0* setpoint. In fact, a *0* setpoint will turn off power to the servo motor, but not its electronic control. Any setpoint input will be forced to lie between MIN_SETPT and MAX_SETPT for the current servo, as long as `servo_limit_check` equals *1*.

Typing 'T' (capital 't') will toggle the `servo_limit_check` variable between *0* and *1*. If the current value is *0*, 'T' will force it to *1* and vice-versa. With `servo_limit_check` equal *0*, you can specify any positive integer as the setpoint. Turning off the limit checks proves quite useful if you need to calibrate a servo (*Section* 10.6, Servo Calibration), including supposedly identical servos!

WARNING! WARNING! WARNING!

With the servo_limit_check variable equal 0, you can overdrive a servo and burn out the motor or electronics within a minute or so. If you do overdrive a servo, quickly change its setpoint to a value within the range of motion of the servo.

Table 3. TALRIK-IV™ Standard Kit Servo and Motor Assignments Highlighted.

SERVO Number	MEKAVR128 Header	SERVO_ENABLE_X X = A for PortA X = C for PortC	TALRIK-IV Assignments
0	PA0	0x01	Pan Servo
1	PA1	0x02	User
2	PA2	0x04	User
3	PA3	0x08	User
4	PA4	0x10	User
5	PA5	0x20	User
6	PA6	0x40	User
7	PA7	0x80	User
8	PC7	0x80	User
9	PC6	0x40	User
10	PC5	0x20	User
11	PC4	0x10	User
12	PC3	0x08	User
13	PC2	0x04	User
14	PC1	0x02	Right Wheel
15	PC0	0x01	Left Wheel

10.6 Servo Calibration

Calibrating the servos means assigning upper and lower limit checks for your particular servos and saving the results in EEPROM (Electrically Erasable Programmable Read Only Memory) for reference by the servo programs. The procedure described here does not apply to servos hacked as gearhead D.C. motors.

1. Enter servo number based upon the port connector to which servo is attached (Table 3).
2. Enter *0* for the servo setpoint to display its servo limits.
3. Turn-off the global variable (`servo_limit_check = 0`) by typing the capital letter 'T'. This step permits you to exceed the servo limits posted.

Calibrate MIN_SETPT of a Servo:

4. Enter servo number.
5. Enter setpoint. First time through use MIN_SETPT.
6. After the servo completes its move, enter the servo number and a setpoint of *0*. The latter disables the servo action.
7. Attempt to rotate the servo output shaft in the direction of the previous motion.
8. If shaft does not rotate, go to *Step 10*, otherwise the servo is not at its true minimum.
9. Repeat *Steps 4 to* 8 with a servo setpoint entry in *Step 5* that is 50 steps less than the current setpoint.
10. If the servo shaft does not rotate with the new setpoint, either the servo is at its minimum setpoint or it is being overdriven.
11. Back-off the setpoint by adding 10 steps.
12. Enter the servo number and a setpoint of *0* and attempt to manually rotate the servo shaft back to the limit position.
13. Repeat *Steps 11* and *12* by adding or subtracting small amounts to the new setpoint, until you can manually rotate the shaft only a small amount to its limit position, at which time you continue with the next step. The main concern is not to overdrive the servo at the minimum setpoint.
14. Type 'L' to save this new MIN_SETPT for the current servo. The display will reflect this new value.
15. Type 'S' to save to EEPROM all servo limits as now constituted. In particular, the new MIN_SETPT you just entered will be saved along with the rest of the current limit values of the other servos.

Calibrate MAX_SETPT of a Servo:

16. Enter servo number.
17. Enter setpoint. First time through use MAX_SETPT.
18. After the servo completes its move, enter the servo number and a setpoint of *0*. The latter disables the servo action.
19. Attempt to rotate the servo output shaft in the direction of the previous motion.
20. If shaft does not rotate, go to *Step 22*, otherwise the servo is not at its true maximum.
21. Repeat *Steps 16 to 20* with a servo setpoint entry in *Step 17* that is 50 steps greater than the current setpoint.
22. If the servo shaft does not rotate with the new setpoint, either the servo is at its maximum setpoint or it is being overdriven.
23. Back-off the setpoint by subtracting 10 steps.

24. Enter the servo number and a setpoint of *0* and attempt to manually rotate the servo shaft back to the limit position.
25. Repeat *Steps 23* and *24* by subtracting or adding small amounts to the new setpoint, until you can manually rotate the shaft only a small amount to its limit position, at which time you continue with the next step. The main concern is not to overdrive the servo at the maximum setpoint.
26. Type 'U' to save this new MAX_SETPT for the current servo. The display will reflect this new value.
27. Type 'S' to save to *EEPROM* all servo limits as now constituted. In particular, the new MAX_SETPT you just entered will be saved along with the rest of the current limit values of the other servos.
28. Repeat the above limit calibrations for each robot that you attach to your robot.

After you have calibrated all the servo limits to their correct values for your robot and saved them as the default values in *EEPROM*, you can display them by typing 'D' (Figure 25). Do not type 'D' before saving changes with 'S', or you will loose the recently determined calibrated values.

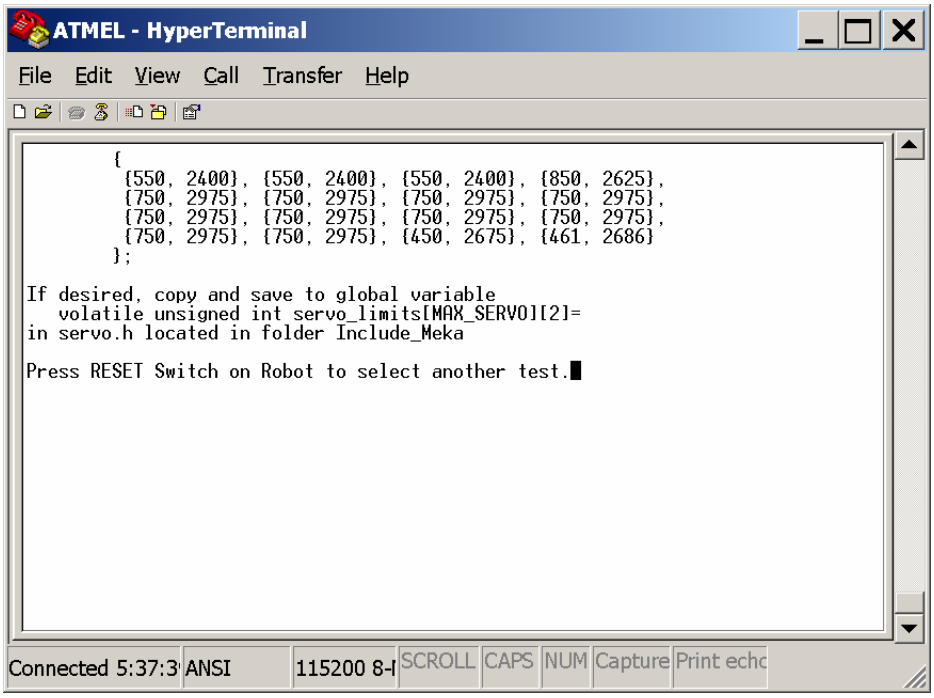


Figure 25. Display of the `servo_limits[MAX_SERVO][2]` values in C-notation.

If you executed 'S' (save to *EEPROM*) at any time in the calibration process, at the next robot reset, the servo variable `servo_limits[MAX_SERVO][2]` in header file `<servo.h>` will be initialized from the *EEPROM* by the macros `ROBOT_INIT` or `ROBOT_AND_SERIAL_INIT`. If you

type 'D' before saving with 'S', you can still salvage your work by copying the matrix from the display and pasting it as the initialization of `servo_limits[MAX_SERVO][2]`. You must then set the global variable

```
unsigned int eeprom_servo_limits_indicator __attribute__((section (".eeprom")));
```

found in `<eeprom_avr.h>` to any value but 0xAAAA. For example, if your program executes

```
eeprom_write_int(&eeprom_servo_limits_indicator, 0);
```

the initialization from the matrix in `<servo.h>` will not be changed to the *EEPROM* values by macros `ROBOT_INIT` or `ROBOT_AND_SERIAL_INIT` at the next reset.

11. *TALRIK-IV™* PLAY

11.1.1 Checkout TALRIK-IV™ Operation with `tk4avr_test.hex`

Refer to *Section 10,* TALRIK-IV™ Testing for details.

11.1.2 Get TALRIK-IV™ Moving

Load `avoidtkavr.hex`. This program demonstrates the IR collision avoidance and bumpers. Although the collision avoidance algorithm in `avoidtkavr.c` operates on a simple principle, *TALRIK-IV™* will avoid most large obstacles. For smaller objects, such as chair legs, the front bumper detects the collision. If you crowd *TALRIK-IV™* with obstacles all about it, it may just spin around in a circle trying, but unable, to get away. You can make the robot less sensitive, by making a copy of this program and changing the threshold for turning away from an object.

11.1.3 Write your own IR Ranging Program

Mount an IR range detector on the panning *Sensor Head*. To do this you may want to drill some holes in the top of the *Sensor Head* to pass *4/40* machine screws and mount the range detector as you would on the robot's top plate. This system can be used to range out to about 1 meter along 180° of arc in front of the robot with maybe 10% accuracy. You will have to calibrate the IR detector as explained in *Section 10,* TALRIK-IV™ Testing.

11.2 Tips for Writing Programs

With few exceptions, you will declare

```
#include <tkIVavr.h>
```

In the main program

```
ROBOT_AND_SERIAL_INIT;
```

will be the first line of executable code if the program uses serial IO, otherwise,

```
ROBOT_INIT;
```

will be the first line of executable code. The second line of code, for those programs that will cause the robot to move, is usually the macro

```
START;
```

which waits for back bumper switch closure before further execution takes place. The program `avoidtkavr.c` illustrates these points.

11.3 Writing your own Interrupt Service Routines for TALRIK-IV™ using avr-gcc

You should not attempt to write interrupt service routines unless you have extensive experience with the ATmega128 and have great familiarity with how interrupts work.

Mekatronix uses the following signals for its interrupt routines:

```
SIGNAL(SIG_OUTPUT_COMPARE3B)        // For TALRIK-IV clock driver

SIGNAL(SIG_OUTPUT_COMPARE3C)        // For TALRIK-IV servo driver
```

Mekatronix strongly advises you not to change existing interrupt service routines.

Caution!!!

If you change any of the standard TALRIK-IV™ drivers, Mekatronix applications and system software will not run correctly.

12. PROGRAMMING BEHAVIOURS

12.1 TALRIK-IV™ and MEKAVR128™ for Robot Behavior Development

Programming behaviors is what autonomous mobile robots is all about, or, at least a substantial part of what its all about! Without being technical, a behavior is whatever the robot does. The emphasis is on action! From the engineering viewpoint, you want to program behaviors that produce useful results. Make a robot vacuum cleaner, or a robot valet. With an artistic eye, you want to program behaviors that esthetically please or excite. Why not make *TALRIK-IV*™ dance? A ballet on wheels! From the scientific perspective you can inquire about the scope of machine intelligence and test your theories on a real robot! Out of intellectual curiosity and the creation urge, you might want to develop physically embodied animats, artificial animals. Develop your own ecology with predator robots that drain the prey robots' batteries and prey robots that hide and avoid predator robots and seek battery recharging stations as food sources. Or, you can tailor a robot to enter many of the robot contests around the world using the *MEKAVR128*™ as your robot controller. While building your robot you can use the *TALRIK-IV*™ to test many of your ideas before committing your own robot design, greatly facilitating implementation. Many of these contests require manipulation and sensors not supplied with *TALRIK-IV*™, but the *TALRIK-IV*™ can often be expanded to meet contest requirements.

12.2 Some Possible Behaviors

TALRIK-IV™ programs provide the basic hardware interrupt and device driver routines for the robot. These allow the user to access the sensor readings and drive the motors and servos. With these routines, the user can program an unlimited number of behaviors. A representative set, but, by no means, an exhaustive set, of primitive set of behaviors, from which more complex ones can be developed, are listed in Table 4.

Table 4 Primitive Behaviors

Collision Avoidance	Collision Detection	Line following	Light following
Light avoidance	Pushing	Collision detection	Shy behavior
Aggressive behavior	Exploring behavior	Wall following	Beacon tracking

With shaft encoders (not included) and the IR ranging sensors, *TALRIK-IV*™ can develop measurement behaviors (Table 5). These behaviors allow *TALRIK-IV*™ to quantify some of its environment. While the measurements taken by these sensors are not precise, *TALRIK-IV*™ can be programmed to perform a number of surprising tasks with the information provided.

Table 5 Measurement Behaviors

Relative headings	Range data	Circumnavigating an object
Length of a path	Wheel speed	Mean free path distance

From the primitive and measurement behaviors, one might, with great skill, have *TALRIK-IV™* perform the behaviors in Table 6. These behaviors are still research issues, so if you come up with something that really works well, let the rest of the robot community know about your results!

Table 6 Complex Behaviors

Make maps	Navigate its own map
Learn about its environment	Develop curiosity about unexplored environments

12.3 Advice on Developing Behaviors

The following advice is based on several years experience teaching engineering students to program autonomous robot behaviors.

12.3.1 Vulcan Mind Meld

To effectively program a behavior for *TALRIK-IV™*, or, quite possibly, any autonomous robot, and gain insight into the problems you face in developing your concept, you should play Vulcan to the robot and imagine a Vulcan mind meld with it. All you Trekkie fans know what this means. But, to be specific, try to perceive the universe as the robot does with its limited capabilities. As you imagine yourself one with the robot, play out different sensations and responses. Help yourself by actually recording robot sense data and examine typical responses, or responses to special environmental conditions of interest in the behavior you are developing. The mind meld will help prevent the common error of asking the robot to respond to environmental conditions it cannot detect with its sensors! While this statement is so totally obvious, it is also a difficult self-discipline to psychologically enforce. Why? Humans typically interact with each other or intelligent animals, expecting and receiving sophisticated behavior and sensory performance. These expectations seem to subconsciously creep into our agenda when working with autonomous machines, often with disappointing results! Autonomous robots have no where near the sensory and behavioral capabilities of an insect, let alone higher animals.

12.3.2 Virtual Mind Meld©[3]

To assist in perceiving the universe as the robot does, you can write host computer programs to generate computer graphic displays that depict the robot's perception in any sense that makes communication with the robot easier. Robot Rorschach tests, color maps…a virtual robot environment. This process we coin as a *Virtual Mind Meld.* The robot transmits data to the host computer which, in turn, portrays the robot reality in a computer graphics medium to create a virtual reality to bridge the species communication barrier.

12.3.3 Relative calibration of sensors of the same type

Manufacturing tolerances, circuit tolerances, and mounting variations make it possible for two instances of the same type of sensor to respond differently to the same stimulus. Behaviors,

[3] Virtual Mind Meld © Mekatronix™

therefore, should not be programmed to depend upon two sensors of the same type producing identical responses to the same stimulus. Instead, program sensors of the same type to relatively calibrate themselves in some fixed environment. For example, place a cardboard box in front of *TALRIK-IV™* and measure the response of the two cross-eyed IR range detectors. Note the differences in the readings. If there are none, that's great! In general, however, they will differ somewhat. The difference in these readings might materially affect some behaviors, so a routine to relative calibrate the responses of the front sensors would provide behavior algorithms a balanced sensor view upon which to act.

If a sensor behaves consistently over time, you can parameterize its characteristics and save those parameters in *EEPROM*, effectively allowing you to write code independent of a particular sensor's characteristics. For example, take *12* sample points of a particular IR range detector response curve to objects at varying distances and record these in *EEPROM*. Any program that uses this IR range detector will just ask the distance from a service routine that extrapolates the answer from the *EEPROM* data. If another version of this sensor on a second *TALRIK-IV™* has also been characterized in its *EEPROM*, the program that ran on the first robot will run on the second without changing threshold values and the like. This powerful concept allows robot groups to share code, as long as they agree where to characterize sensors in *EEPROM*.

12.3.4 Adjusting to Ambient Conditions

A programmed behavior will often be *brittle*, not flexible or adaptive, if that behavior depends upon specific magnitudes of robot sensor readings. Brittle behaviors fail when the environment changes from the environment in which the behavior was developed. The smaller the change that causes the failure, the more brittle that behavior is.

Robot behaviors and sensors, therefore, should adjust to ambient conditions. Biological organisms perform this function fantastically well. The human eye adjusts to bright sunlight or a darkened cathedral with dimly lit candles. This procedure is easier to state then execute, but serves as a general principle.

12.3.5 Create simple behaviors

The beginning robot practitioner usually formulates behaviors too complicated to implement directly. With experience, the virtue of simple, direct behaviors become apparent. Complex behaviors should be broken down into sequences of simple, primitive behaviors. If this can be done, the chances of successful implementation are high. If not, there is little value in trying to implement such behaviors directly.

12.3.6 Build on simple behaviors

As the user accumulates a repertoire of primitive behaviors, complex behaviors open up. Perhaps the easiest way to generate complex behaviors is simply to sequence a collection of primitive behaviors. For example, wall following might be decomposed as follows:

1) Detect a "large" object,
2) Approach the object until "near",
3) Turn until the robot front-to-rear axis to align "parallel" with the "surface" of the obstacle,
4) Move "parallel" to the obstacle surface.

At each instant of time a particular behavior in the sequence is invoked based on the current state of the robot and its sensory inputs. Of course, the programmer will have to establish to the robot's perception the meaning of such terms as "large", "near", "surface", and "parallel". Remember to Vulcan Mind Meld!

12.4 Integrating Behaviors

More complex behaviors may require the combination of primitive behaviors in a way not well understood. Neural network activation, non-linear dynamics, and fuzzy logic all offer techniques for integrating behaviors. Each technique offers specific advantages and specific difficulties. Discussion of such issues is beyond the scope of this manual. The reader's attention is brought to this matter to encourage investigation into these possibilities.

Enjoy your robot!