Heated stage system for small rodents – Zeiss inverted microscope

1. System description:

This system is intended to be used with 'single-port' window chambers, imaged using a Zeiss inverted microscope and is intended to maintain a suitably warm environment around the window chamber and the lower part of the animal, while the rest of the animal's environment is controlled by an enclosure around the microscope. The system described here consists of the following:

A stage insert which fits an existing motorised Märzhauser inverted stage and which contains two plate heaters and a temperature sensor, as well as a clamping arrangement to hold a coaxial anaesthetic gas delivery and waste tube.

An electronic temperature controller which delivers an appropriate quantity of electrical power to the plate heaters so as to maintain the user-set surface temperature; this unit is fitted with a USB interface which may be used in conjunction with an optional software package.

A wall plug power supply, delivering +12V at a maximum current of ~1 A, supplying raw power to the system.

An optional software application which may be used to display the time course of temperature settling and variations, as well as setting relevant control parameters

The hardware parts of the system are shown in Figure 1.

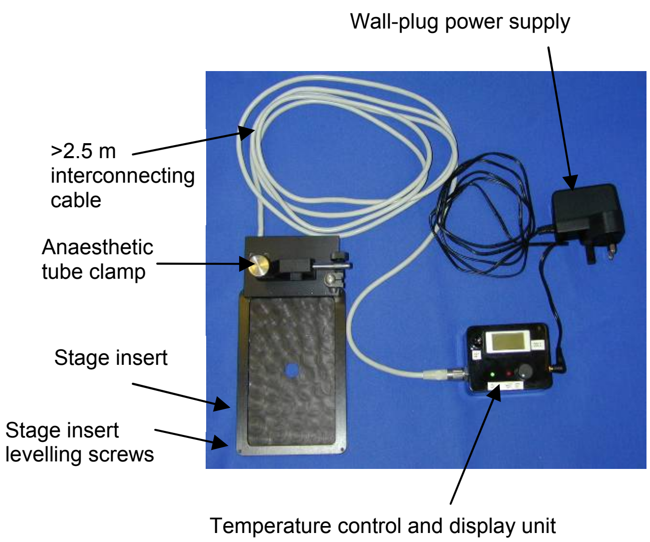


Figure 1: System components: the stage insert and anaesthetic clamp assembly are connected to a temperature control and display unit through a ~2.5 m long multi-core cable. This unit also houses a USB interface and is connected to a wall-plug power supply through a standard jack (2.1 mm). The control unit contains a temperature display, a temperature set control, a 'power on' indicator (green) and a 'heating' indicator (red); a push-switch to the side of the display allows the latter to display either the actual temperature or the set temperature. Temperature display is in degC.

The use of the system is (hopefully!) fairly intuitive. The user should first adjust the four levelling screws at the corners of the insert so that the insert is level (minimising focus variations with stage movement) and so that it fits snugly in the stage. The wall plug power supply is then connected and the appropriate target temperature set; this is done by pressing down the switch next to the temperature indicator and turning the 'set' control (clockwise = higher temperature) until the appropriate reading is obtained. The range of that control is limited to around 38 degrees so as to prevent possible overheating. The temperature display is capable of displaying temperatures up to around 43 degrees. Details of the controls are shown in Figure 2. The system is able to operate independently of any software, but an optional USB interface is available should the user wish to log the performance.

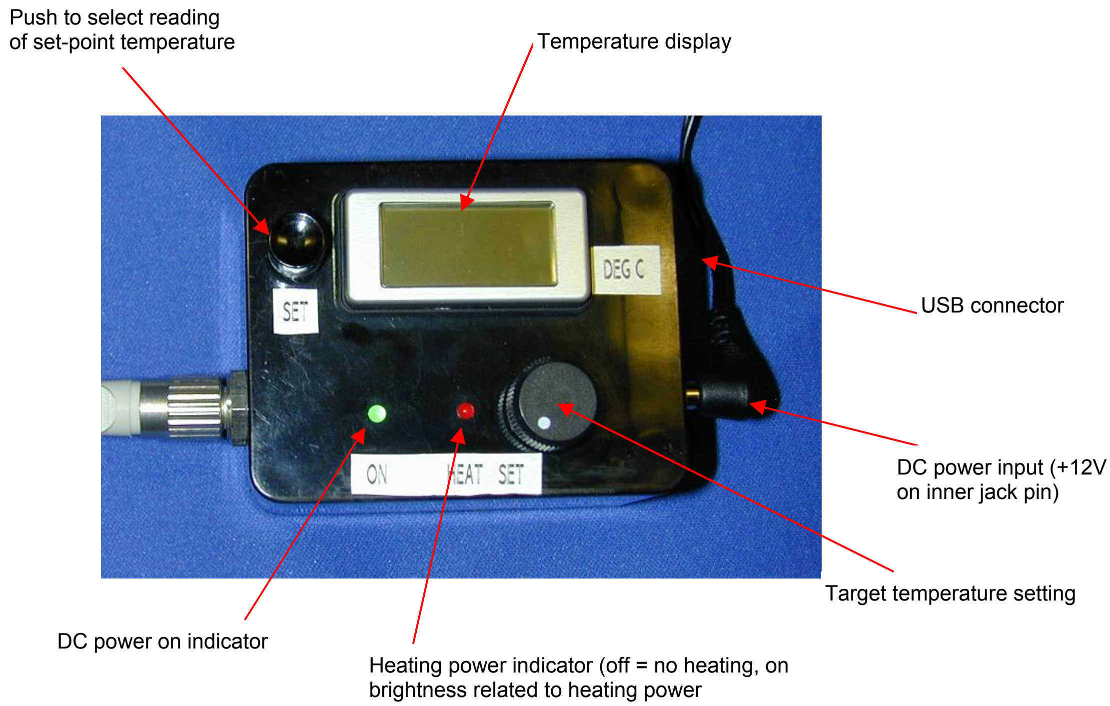


Figure 2: Details of controls on the system temperature control unit

The mechanics of the system are shown in Figure 3. Two heating pads are coupled to a copper plate to ensure an even temperature distribution and good thermal contact to a solid-state temperature sensor placed in contact with the copper plate. An anodised aluminium plate is thermally bonded to the copper plate and is used to prevent inevitable potential corrosion.

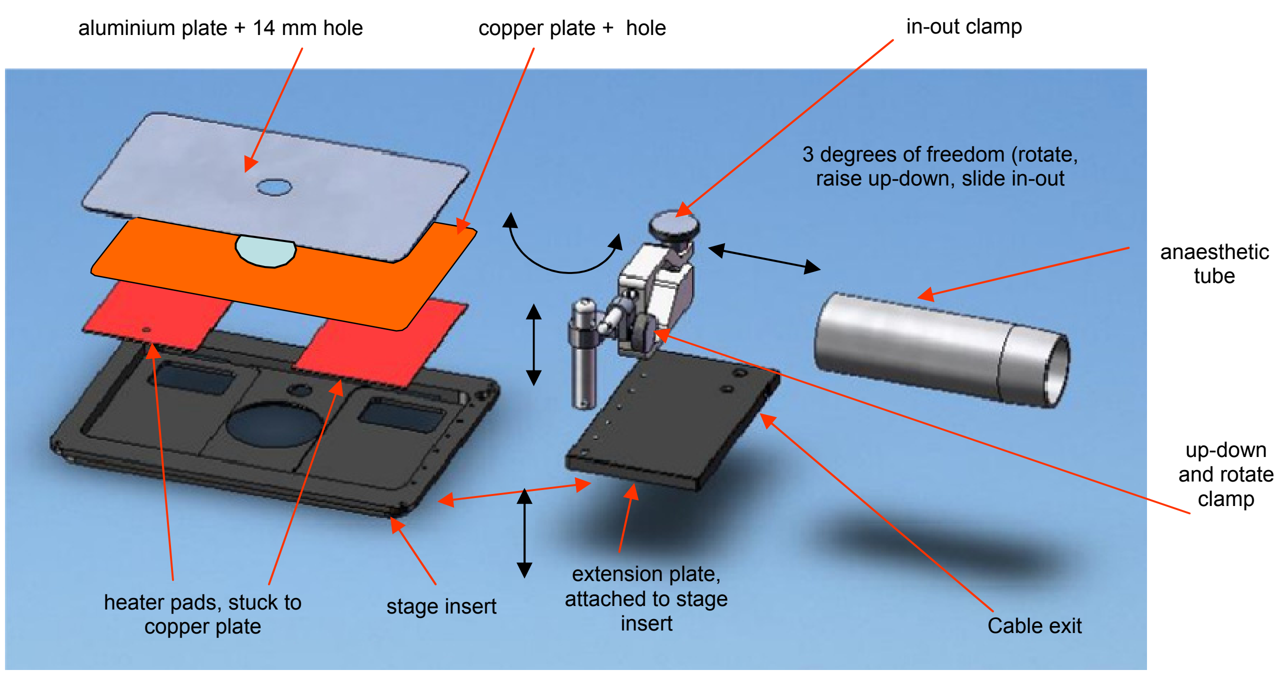


Figure 3: Details of stage insert construction

2. Circuit description:

The circuit is based around a DLP245 PB-G module which has a USB interface and a 16F877A microprocessor. The 16F877A has a number of analogue inputs which are used to implement a proportional-integral-derivative (PID) control loop, driving the heaters with a pulse-width modulated (PWM) output. The circuit is shown in Figure 4.

An LM62 temperature sensor provides an output scaled at 15.6 mVdegC^{-1} and offset by around 480 mV. Am LM4040 reference is used, in conjunction with a LT1013 operational amplifier to provide a DC output such that 20 degC = +2V and 40 degC = +4V. This output is attenuated to provide 20mV-40mV signal which is fed to a digital panel meter of 200 mV sensitivity. An indication of actual temperature, with a 0.1 degC resolution is thus obtained. The non-attenuated temperature signal is also fed to the 16F877A's analogue-to-digital converters (A-Ds). The reference also drives the set-point control potentiometer, the output of which is fed to one of the other A-Ds; these two signals drive the PID loop. The A-Ds full-scale range is set by additional inputs driven from signal ground and the reference voltage, nominally 4.096 V. The loop output is a PWM signal which drives ground-referenced heaters through two MOSFETs, 2N7000 driver (n-channel) and IRF 5210 output switch (p-channel). A maximum heater power of 7.5W is available, though the maximum on-time of the PWM output may be further restricted by an internal signal derived from an additional analogue input, defined by a preset.

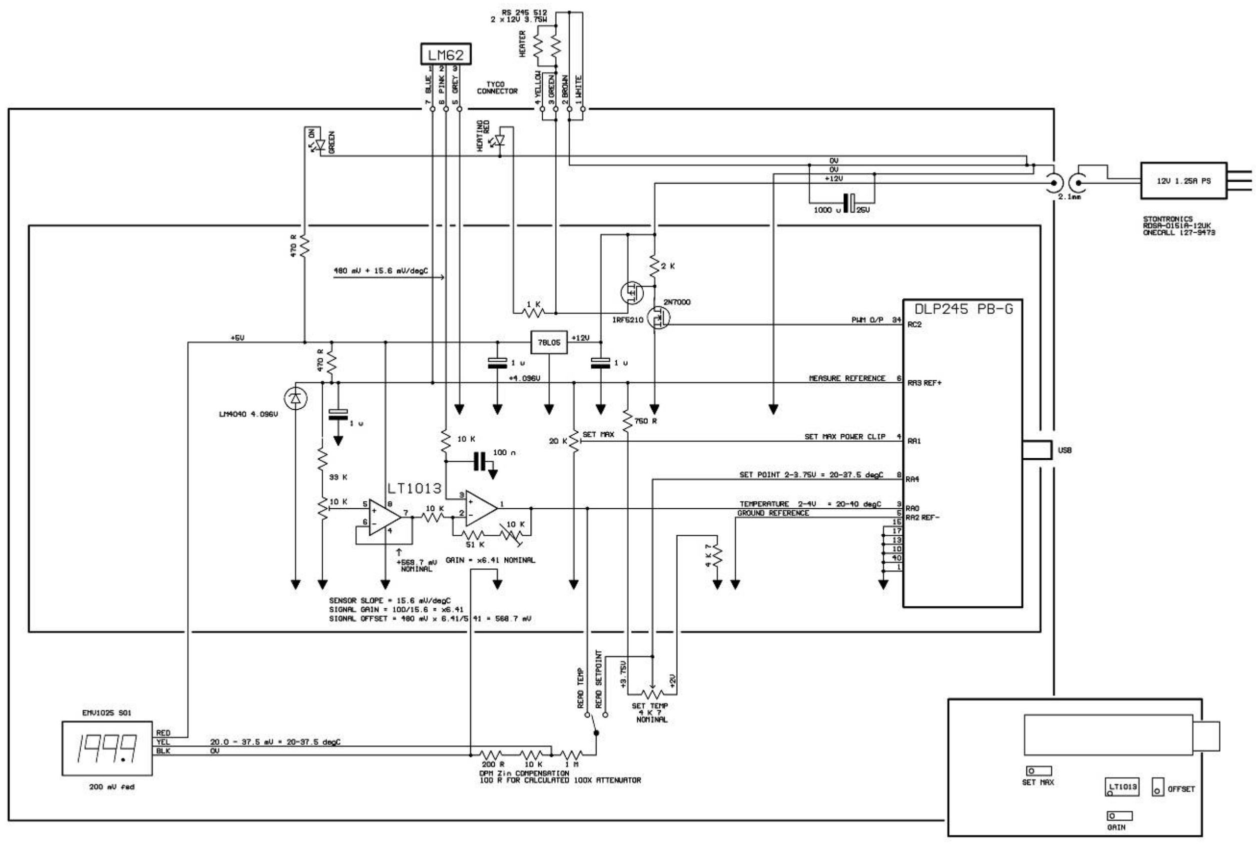


Figure 4: Circuit diagram of the temperature controller.

The repetition rate of the PWM signal is made slow (~1.22 kHz) to simplify MOSFET drive requirements. The firmware code on the 16F877A microcontroller is based around a PID control feedback loop. The proportional, integral and derivative gains are stored in the microcontrollers internal EEPROM. After initialising I/O pins connected with the USB communication to the PC and setting up the PWM unit, A/D converter circuits and timer interrupt, the program enters a control loop where the microcontroller checks for any USB communication until a timed interrupt allows the PID control to start. The PID timer interrupt is set to 20 ms.

Three voltages are read on the A/D converter channels which relate to actual temperature, set point temperature and maximum set power to the heaters. These are read successively 64 times and the readings are added together. The totals are then divided by 64 to give an average reading for each of the channels. The program then enters the PID control where the actual temperature is compared to the set point temperature. The integral, derivative and proportional terms are calculated and with suitable scaling, a number is derived at which can be entered into the PWM control. This sets the amount of power delivered to the heater mats in the stage insert. The maximum power reading limits the upper range of the PWM control.

3. PIC firmware:

The firmware stored in the microcontroller is shown below. We note that we acquire analogue data on three channels (representing the set-point, the actual temperature and the maximum heater power). The analogue values are referenced to an internal reference and the PIC analogue-to-digital converters can operate with respect to this reference and signal ground (supplied to RA3 and RA2 respectively). The analogue-to-digital converters take 20 µs to complete a conversion and require a delay time of 20 µs between conversions when changing channels, so when digitising three inputs, the total time taken is 120 µs. Since the converters operate with 10 bit resolution, we acquire 64 such sets of values and end up with 16 bit numbers with simple addition (going above 16 bits would have required significantly more complex code and a slower overall response time. We thus spend 120 µs x 64 = 7.680 ms acquiring one block of data. We provide an interrupt with a 20 ms period which triggers this 7.68 ms acquisition sequence. We thus end up with a useful reduction of potential AC mains-induced interference.

We also note that we use a software-defined proportional integral-derivative feedback loop (see for example http://www.jashaw.com/pid/tutorial/). However implementing this digitally requires the application of various scaling factors in order to keep variables with the 16 bit integer dynamic range. The proportional, integral and derivative gains are set from the high level C-code program, described later, so as to be able to adjust them conveniently and obtain minimal overshoot and fast settling. We modelled our code on the AN964A Microchip application note (http://www.microchip.com/). Heater power is determined by using the PIC PWM routines.

```
//*********************************************************************************
//
// File:    heater mat control.c
// Date:    29/10/10
//
//*********************************************************************************
#include "heater mat thermostat.h"
/* 16F877A bytes */
/* Change it per chip */
#byte PIC_SSPBUF=0x13
#byte PIC_SSPADD=0x93
#byte PIC_SSPSTAT=0x94
#byte PIC_SSPCON1=0x14
#byte PIC_TMR1L=0x0E
#byte PIC_TMR1H=0x0F
#byte PIC_INTCON=0x0B
#byte PIC_PWM1CON=0x1C
#byte PIC_CCP1CON=0x17
#byte PIC_CCPR1L=0x15
#byte PIC_EECON1=0x18C
#byte PIC_OPTION=0x81

/* Bit defines */
#define PIC_SSPSTAT_BIT_SMP        0x80
#define PIC_SSPSTAT_BIT_CKE        0x40
#define PIC_SSPSTAT_BIT_DA         0x20
#define PIC_SSPSTAT_BIT_P          0x10
#define PIC_SSPSTAT_BIT_S          0x08
#define PIC_SSPSTAT_BIT_RW         0x04
#define PIC_SSPSTAT_BIT_UA         0x02
#define PIC_SSPSTAT_BIT_BF         0x01

#define PIC_SSPCON1_BIT_WCOL       0x80
```

```
#define PIC_SSPCON1_BIT_SSPOV          0x40
#define PIC_SSPCON1_BIT_SSPEN          0x20
#define PIC_SSPCON1_BIT_CKP            0x10
#define PIC_SSPCON1_BIT_SSPM3          0x08
#define PIC_SSPCON1_BIT_SSPM2          0x04
#define PIC_SSPCON1_BIT_SSPM1          0x02
#define PIC_SSPCON1_BIT_SSPM0          0x01
#define PIC_INTCON_BIT_INTF            0x02
#define PIC_WREN  0x04                                          //EEPROM write enable bit 0=inhibits write
//Control pins
#define RXF PIN_E1                                              // Receive pin
#define TXE PIN_E2                                              // Transmit pin
#define RD  PIN_B1                                              // Read pin
#define WR  PIN_B2                                              // Write pin

#define numAdcReadings 64                                       //Set the number of adc readings to be added together
#define derivative_SF  10                                       //Derivative scaling factor
#define integral_SF  1023                                       //Integral scaling factor
#define offset  0                                               //1023=41 degC 1degC=25
#define resolution   1024                                       //Resolution of PWM
//#define setPIDcounter  200                                    //Number of interrupts for 20ms on timer0 with div_2 prescaler
#define setPIDcounter  400                                      //For div_1 prescaler

void Init(void);
void PID(void);
int dataTest(void);
int getData(void);
void Set_Constants();
unsigned int16 ADConversions(int);
int ReadADChannels(void);
int handle_PID_val(void);
int handle_PID_read(void);
int handle_A_D_inputs(void);
void writeData(int);
void WriteEeprom(void);
int ack_return(void);
void EnableEEPROMWrite(void);
void DisableEEPROMWrite(void);

int1 do_PIDfg;
int kp_L,ki_L,kd_L,kp_M,ki_M,kd_M,SetTempVal_L,SetTempVal_M;
int busy=0,numBytes;
int I_O_inbytes[10];

unsigned int16 ki, kd, kp,term1_char, term2_char,temp_int;
unsigned int16 temp_set_point,measured_temp,PID_counter;
unsigned int32 max_power,set_max_power;
signed int32 Cn,SumE,integral_term;
signed int16 derivative_term,SumE_Min, SumE_Max,en0, en1, en2, en3, en4, en5;

#INT_TIMER0
timer0_isr()
{
  set_timer0(40);                                               //To interrupt at 50us

   PID_counter=(PID_counter-1);                                 //Count down
  if(PID_counter==0){

     do_PIDfg=1;                                                //Set flag to read
  }

  return 0;
}
//*****************************************************************************
//    The form of the PID is C(n) = K(E(n) + (Ts/Ti)SumE + (Td/Ts)[E(n) - E(n-1)])
//*****************************************************************************
void PID()                                                      //The form of the PID is C(n) = K(E(n) + (Ts/Ti)SumE + (Td/Ts)[E(n) - E(n-1)])
{
int16  duty_cycle_zero;

  integral_term = derivative_term = 0;

// Calculate the integral term
  en0=(en0 - (temp_set_point - offset));                        //Error value range from +/- 1023

  SumE = SumE + en0;                                            //SumE is the summation of the error terms
  if(SumE > SumE_Max){                                          //Test if the summation is too big
    SumE = SumE_Max;
  }
  if(SumE < SumE_Min){                                          //Test if the summation is too small
    SumE = SumE_Min;
  }                                                             //Integral term is (Ts/Ti)*SumE where Ti is Kp/Ki
                                                                //and Ts is the sampling period
                                                                //actual equation used to calculate the integral term is
                                                                //Ki*SumE/(Kp*Fs*X) where X is an unknown scaling factor
                                                                //and Fs is the sampling frequency
  integral_term = SumE / 50;                                    //Divide by the sampling frequency and scaling factor
  integral_term = integral_term * ki;                           //Multiply Ki
  integral_term = integral_term /integral_SF;

// Calculate the derivative term
  derivative_term = en0 - en5;

  if(derivative_term >= 120){                                   //Test if too large
```

```
    derivative_term = 120;
  }
  if(derivative_term <= -120){                                  //Test if too small
    derivative_term = -120;
  }                                                             //Calculate derivative term using (Td/Ts)[E(n) - E(n-1)]
                                                                //where Td is Kd/Kp
                                                                //actual equation used is Kd(en0-en3)/(Kp*X*3*Ts)
 derivative_term = derivative_term * kd;                        //where X is an unknown scaling factor

  if(derivative_term >= 120){
    derivative_term = 120;
  }
  if(derivative_term <= -120){
    derivative_term = -120;
  }
  Cn = en0 + integral_term + derivative_term;                   //Sum the terms
//  Cn = ((Cn * kp)/1023) ;                                     //multiply by Kp then scale
  Cn = ((Cn * kp)/512) ;
 if(Cn >= 1023){                                                //Used to limit duty cycle
    Cn = 1023;
  }
 if(Cn <= -1023){
    Cn = -1023;
  }

 if(Cn >0){
    duty_cycle_zero=0;
    set_pwm1_duty (duty_cycle_zero);                            //Function needs 16 bit integer
  }
 if(Cn <= 0){
   Cn = abs(Cn);
    if(Cn > set_max_power){
      Cn = set_max_power;
    }
   set_pwm1_duty (Cn);
   }
  en5 = en4;
  en4 = en3;
  en3 = en2;                                                    // Shift error signals
  en2 = en1;
  en1 = en0;
  en0 = 0;

  return;
}
//*************************************************************************
unsigned int16 ADConversions(chanNum)
{
    set_adc_channel(chanNum);
    delay_us(20);                                               //Delay for channel switching to settle

          return read_adc();
}
//*************************************************************************
void DisableEEPROMWrite(void)
{
          PIC_EECON1=PIC_EECON1 & 0xfb;                         //EEPROM write enable bit=0 inhibits write
}
//*************************************************************************
void EnableEEPROMWrite(void)
{
          PIC_EECON1=PIC_EECON1 | 0x04;                         //EEPROM write enable bit=1 enables write
}
//***************************************************************************
//Set constants
//***************************************************************************
void Set_Constants()
{
  kp=read_eeprom (1);                                           //Read constants from memory
  kp_L=read_eeprom (2);
  kp=(kp<<8 | kp_L);
  ki=read_eeprom (3);
  ki_L=read_eeprom (4);
  ki=(ki<<8 | ki_L);
  kd=read_eeprom (5);
  kd_L=read_eeprom (6);
  kd=(kd<<8 | kd_L);

}
////////////////////////////////////////////////////////////////////////////////
int dataTest()
{
int state;

  state=input_state(RXF);                                       //Tests if data present
  if(state==0 && busy==0){                                      //If not busy
    busy=1;
    getData();
    busy=0;
   }
 return 0;
}
////////////////////////////////////////////////////////////////////////////////
int getData(void)
```

```
{

int command;

   output_bit(RD,0);                                    //RD pin low
   command=input_D();                                   //Read the first byte this is command
   output_bit(RD,1);                                    //RD pin high

   //go to dig_IO, AD_read to handle the command
 switch(command)
 {
   case 1:                                              //PID values
   handle_PID_val();
   break;
   case 2:
   break;
   case 3:
   WriteEeprom();                                       //Store PID values in memory
   ack_return();
   break;
   case 4:                                              //Read PID values
   handle_PID_read();
   ack_return();
   break;
   case 5:                                              //Read A/D inputs
   handle_A_D_inputs();
   ack_return();
   break;
   case 6:
   break;
}
   return 0;
}
int handle_PID_val(void)
{
int1 state;
int x;

   output_bit(RD,1);                                    //RD pin high
   state=input_state(RXF);                              //Tests if data ready
   while(state==1){
      state=input_state(RXF);                           //Tests if data ready
     }
     output_bit(RD,0);                                  //RD pin low
     numBytes=input_D();                                //Read the number of data bytes
     output_bit(RD,1);                                  //RD pin high

    for(x=0;x<=(numBytes-3);x++){                       //Read rest of the data
       state=input_state(RXF);                          //Tests if data ready
     while(state==1){
       state=input_state(RXF);                          //Tests if data ready
      }
        output_bit(RD,0);                               //RD pin low
        I_O_inbytes[x]=input_D();                       //Store in array
        output_bit(RD,1);                               //RD pin high

    }
    kp = I_O_inbytes[0];
    ki = I_O_inbytes[2];
    kd = I_O_inbytes[4];
    kp = (( kp<<8) | I_O_inbytes[1]);
    ki = (( ki<<8) | I_O_inbytes[3]);
    kd = (( kd<<8) | I_O_inbytes[5]);

     state=input_state(TXE);                            //Sends acknowledge at end of sequence
      while(state==1){
         state=input_state(TXE);                        //Tests if module ready
        }
     output_D(0x04);                                    //Send acknowledge
     output_bit(WR,1);                                  //WR Pin high to low to actually write
     output_bit(WR,0);                                  //WR low

return 0;
}

 void WriteEeprom()                                     //Store PID values in memory
 {

 kp_M = kp>>8;                                          //Separate 16 bit integer into two 8 bit integers
 kp_L = kp & 0xff;

 ki_M = ki>>8;
 ki_L = ki & 0xff;

 kd_M = kd>>8;
 kd_L = kd & 0xff;

 SetTempVal_M = temp_set_point>>8;
 SetTempVal_L = temp_set_point & 0xff;
 EnableEEPROMWrite();

 write_eeprom (1,kp_M);                                 //Write values to EEPROM
 write_eeprom (2,kp_L);
 write_eeprom (3,ki_M);
```

```
 write_eeprom (4,ki_L);
 write_eeprom (5,kd_M);
 write_eeprom (6,kd_L);
 write_eeprom (7,SetTempVal_M);
 write_eeprom (8,SetTempVal_L);

 DisableEEPROMWrite();
 }
 //---------------------------------------------------------------------
int handle_PID_read(void)
{
   kp_M=read_eeprom (1);                                    //Read PID values from memory
   kp_L=read_eeprom (2);

   ki_M=read_eeprom (3);
   ki_L=read_eeprom (4);

   kd_M=read_eeprom (5);
   kd_L=read_eeprom (6);

  writeData(Kp_M);
  writeData(Kp_L);
  writeData(Ki_M);
  writeData(Ki_L);
  writeData(Kd_M);
  writeData(Kd_L);
  return 0;
}
//--------------------------------------------------------------------------
int handle_A_D_inputs(void)
 {
 unsigned int en0_M,en0_L,max_power_M, max_power_L,temp_set_point_M,temp_set_point_L;

 en0_M = measured_temp>>8;
 en0_L = measured_temp & 0xff;

 max_power_M = max_power>>8;
 max_power_L = max_power & 0xff;
 temp_set_point_M = temp_set_point>>8;
 temp_set_point_L = temp_set_point & 0xff;
 writeData(en0_M);
 writeData(en0_L);
 writeData(max_power_M);
 writeData(max_power_L);
 writeData(temp_set_point_M);
 writeData(temp_set_point_L);

 return 0;
 }
//--------------------------------------------------------------------------
void writeData(data)                                        //Write data back to PC
{
int state=1;

      state=input_state(TXE);
  while(state==1){
      state=input_state(TXE);                               //Tests if module ready
     }
    output_D(data);                                         //Set the output data
    output_bit(WR,1);                                       //WR Pin high to low to actually write
    output_bit(WR,0);                                       //WR low
}
//-----------------------------------------------------------------------
int ack_return(void)
{
int state;

    state=input_state(TXE);                                 //Sends acknowledge at end of sequence
      while(state==1){
        state=input_state(TXE);                             //Tests if module ready
       }
    output_D(0x04);                                         //Send acknowledge byte
    output_bit(WR,1);                                       //WR Pin high to low to actually write
    output_bit(WR,0);                                       //WR low

    return 0;
}

//****************************************************************************
//Initialisation routine
//****************************************************************************
void Init()
{
int state;

   output_bit(RD,1);                                        //Pin B1 high
   output_bit(WR,0);                                        //Pin B2 low
   state=input_state(RXF);                                  //Make RXF input
   state=input_state(TXE);                                  //Make TXE input

   setup_timer_0(T0_INTERNAL | T0_DIV_1 );                  //If div_1 need 391 interrupts or 400 with set_timer0(40)
 //  setup_timer_0(T0_INTERNAL | T0_DIV_2 );                //Set timer0 prescalar and clock,need 200 interrupts set_timer0(26)
   set_timer0(40); //Use with T0_DIV_1 and 400 interrupts for 20ms
   setup_ccp1(CCP_PWM);   //Set for PWM output
```

```
  setup_timer_2(T2_DIV_BY_16,254,1);                    //Set PWM frequency to 1.225KHz resolution 0-1023
//setup_timer_2(T2_DIV_BY_1,255,1);                     //Set PWM frequency to 19.55KHz resolution 0-1023…useful for other applications…
//setup_timer_2(T2_DIV_BY_1,149,1);                     //Set PWM frequency to 20KHz resolution 0-1000
//setup_timer_2(T2_DIV_BY_1,155,1);                     //Set PWM frequency to 32KHz resolution 0-624
//setup_timer_2(T2_DIV_BY_1,159,1);                     //Set PWM frequency to 31.25KHz resolution 0-640
//setup_timer_2(T2_DIV_BY_1,49,1);                      //Set PWM frequency to 100KHz resolution 0-200
  PID_counter = setPIDcounter;
  en0 = en1 = en2 = en3 = en4 = en5 = term1_char = term2_char =0;
  ki = kd = 0;
  kp = 100;
  temp_int = integral_term = derivative_term =0;
  SumE_Max = 30000;
  SumE_Min = 1 - SumE_Max;
  setup_adc_ports( AN0_AN1_AN4_VREF_VREF );             //A/D inputs A0 A1 A4 VRefh=A3 VRefl=A2
  setup_adc(ADC_CLOCK_DIV_32);    //For 20MHz

}
//***************************************************************************
//Main() - Main Routine
//***************************************************************************
void main()
{
int16 total_actualTemp,total_setPointTemp,total_max_power,actualTemp, setPointTemp;
int x,state;

  DisableEEPROMWrite();                                 //Disable EEPROM write
  Init();                                               //Initialize 16F877A Microcontroller
  Set_Constants();                                      //Get PID coefficients ki, kp and kd
       state=input_state(RXF);                          //Tests if any data in buffer already
  while(state==0){                                      //Clear data in buffer if any
      output_bit(RD,0);                                 //Pin RD low
      output_bit(RD,1);                                 //Pin RD high
    state=input_state(RXF);
   }

  enable_interrupts(INT_TIMER0);
  enable_interrupts(GLOBAL);
  while(1)                                              //Loop Forever
  {
     output_bit(PIN_C0,1);                              //Test pulse
     dataTest();                                        //Check for USB communication

    if(do_PIDfg==1){
       output_bit(PIN_C0,0);
        do_PIDfg=0;                                     //Reset PID flag
        PID_counter=setPIDcounter;                      //Reset counter
        total_actualTemp=0;                             //Zero summations
        total_setPointTemp=0;
        total_max_power=0;

        for(x=1;x<=numAdcReadings;x++){                 //Take number of readings
          actualTemp=ADConversions(0);                  //Read ADC channel 0, actual temperature
          total_actualTemp=actualTemp+total_actualTemp;
          setPointTemp=ADConversions(4);                //Set point temperature
          total_setPointTemp= setPointTemp+total_setPointTemp;
          max_power=ADConversions(1);                   //Read ADC channel 1(max power clip)
          total_max_power= max_power+total_max_power;
        }
        en0=total_actualTemp/numAdcReadings;            //To get value 0 to 1023
        measured_temp=total_actualTemp/numAdcReadings;  //Read back over USB

        temp_set_point=total_setPointTemp/numAdcReadings;  //To get value 0 to 1023
        max_power=total_max_power/numAdcReadings;       //To get value 0 to 1023
        set_max_power=((max_power*resolution)/1023);    //Max power dependant on PWM resolution

        PID();
    }
  }
}
```

4. PIC configuration / internal fuse file

"heater mat thermostat.h

```
#include <16F877A.h>            //Device file
#device adc=10                  //10 bit ADC conversion
#device ICD=TRUE                //For debugging
#FUSES HS                       //High speed Osc (> 4mhz)
#FUSES NOPROTECT                //Code not protected from reading
#FUSES PUT                      //Power Up Timer
#use delay(clock=20000000)      //Define clock speed for delay function
```

5. High level software description:

The software communicates with the control unit over a USB link. The set point and actual temperatures along with the maximum power setting are read at 50ms. The temperature readings are displayed on the basic user panel. Twenty of these readings are stored in an array and then averaged and plotted on a strip-chart which may be displayed when the chart button on the user panel is pressed. The timings produce a point every 1 second.

A further control panel can be accessed by pressing a hidden button on the user panel. This gives the ability to set the PID parameters used in the controller, read the values stored in the microcontroller memory and read the value set for the maximum power available to the heaters. This panel is not designed to be user accessible, but is shown for completeness in the left part of Figure 5. The basic software panel accessible to the user is shown in the right portion of Figure 5.

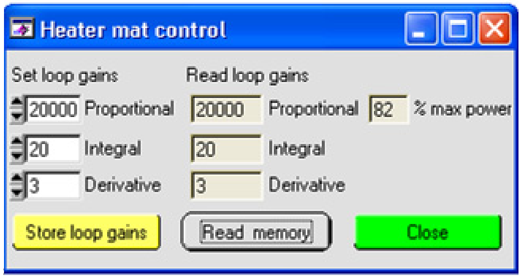
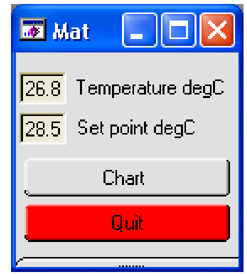


Figure 5: The settings panel.



We now list the high level code, developed under LabWindows CVI (http://www.ni.com/lwcvi/).

```
#include "cvixml.h"
#include <rs232.h>
#include <ansi_c.h>
#include <cvirte.h>
#include <userint.h>
#include "utility.h"
#include "formatio.h"
#include  <analysis.h>
#include "DeviceFinder.h"
#include "heater mat ctrl_ui.h"
#include "IO_interface_v2.h"
#include "usbconverter_v2.h"
#include "DeviceManager.h"

static int PORT;
static int HtrMatCtrlPanel,ReadEepromPanel;

static int initI2Cport(void);
static int ManageDevice(char* device, int enable);
static void GCI_init_heater_mat_ctrl(void);
static void SendPIDValues(void);
static void ReadPIDValues(void);


int main (int argc, char *argv[])
{
	if (InitCVIRTE (0, argv, 0) == 0)
		return -1;   /* out of memory */
	if ((HtrMatCtrlPanel = LoadPanel (0, "heater mat ctrl_ui.uir", HRTMATPNL)) < 0)
		return -1;
	if ((ReadEepromPanel = LoadPanel (0, "heater mat ctrl_ui.uir", READEEPROM)) < 0)
		return -1;

	if(initI2Cport()==-1)return 0;						//Set port number

	DisplayPanel (HtrMatCtrlPanel);
//	RecallSettings();
	GCI_EnableLowLevelErrorReporting(1);
	Delay(1.0);
	GCI_init_heater_mat_ctrl();
//	SetCtrlAttribute (HtrMatCtrlPanel, HRTMATPNL_TIMER, ATTR_ENABLED, 1);	//Enable timer
	RunUserInterface ();
	DiscardPanel (HtrMatCtrlPanel);
	GCI_closeI2C();
	return 0;
}

static int getFTDIport(int *PORT)
{
char path[MAX_PATHNAME_LEN],ID[20];
int id_panel,pnl,ctrl;

//If we are using an FTDI gizmo Device Finder will give us the port number

	GetProjectDir (path);
	strcat(path,"\\");

	strcat(path, "heater matID.txt");
	return selectPortForDevice(path, PORT, "Select Port for heater mat");


}
```

```
static int initI2Cport()
{
int  err,ans;
char port_string[10];

if (getFTDIport(&PORT) == 0)
		sprintf(port_string, "COM%d",PORT);
	else {   //Device not found or not using FTDI. Use some other mechanism //such as Glenn's COM port allocation module.

		while(getFTDIport(&PORT) != 0){
			ans=ConfirmPopup ("Comms error", "Try plugging USB cable in or do you want to quit?");
			if(ans==1){   //quit
					return -1;

			}
		}
	}
	sprintf(port_string, "COM%d",PORT);
	err = OpenComConfig (PORT, port_string, 9600, 0, 8, 1, 512, 512);

	SetComTime (PORT, 1.0);								//Set port time-out to 1 sec
	FlushInQ (PORT);
	FlushOutQ (PORT);
	return 0;

}

static void GCI_init_heater_mat_ctrl(void)
{

  ReadPIDValues();

}

static void SendPIDValues(void)
{
int prop_val,integral_val,derivitive_val;
char val1[20],data_ret[10],msg[256];
int data,stat,cmd,num_bytes;


	while (GetInQLen (PORT)) {							//dump bytes which shouldn't be there
		if (rs232err < 0) ;
		ComRdByte(PORT);
	}

		GetCtrlVal(HtrMatCtrlPanel, HRTMATPNL_PROP,&prop_val);
		GetCtrlVal(HtrMatCtrlPanel, HRTMATPNL_INTERGRAL,&integral_val);
		GetCtrlVal(HtrMatCtrlPanel, HRTMATPNL_DERIVITIVE,&derivitive_val);

		num_bytes = 8;
		cmd = 1;								//Command for PID setting values
		val1[0] = cmd;
		val1[1] = num_bytes;							//Number of bytes
		val1[2] = prop_val>>8;
		val1[3] = prop_val & 0xFF;
		val1[4] = integral_val>>8;
		val1[5] = integral_val & 0xFF;
		val1[6] = derivitive_val>>8;
		val1[7] = derivitive_val & 0xFF;

		ComWrt(PORT, val1, num_bytes);

		data_ret[0]=0;								//Clear array

//		stat = GetInQLen(PORT);
		ComRd(PORT, data_ret,1);						//Read ack
		if(data_ret[0]!=4){
			sprintf(msg, "ACK-ERROR");
			MessagePopup("USB: ",msg);
		}

}
static void ReadPIDValues(void)
{
char val1[20],data_ret[10],msg[256];
unsigned int stat,cmd,num_bytes,prop_val,integral_val,derivitive_val;
unsigned int prop_val_l,integral_val_l,derivitive_val_l;

	num_bytes = 1;
		cmd = 4;								//Command for reading PID values
		val1[0] = cmd;

		ComWrt(PORT, val1, num_bytes);

		data_ret[6]=0;								//Clear array

	//	stat = GetInQLen(PORT);
		ComRd(PORT, data_ret,7);						//Read data
		if(data_ret[6]!=4){
			sprintf(msg, "ACK-ERROR");
			MessagePopup("USB: ",msg);
		}
  prop_val =  data_ret[0] & 0xff ;
```

```
   prop_val_l =  data_ret[1] & 0xff;

   integral_val =  data_ret[2]& 0xff;
   integral_val_l =  data_ret[3]& 0xff;

   derivitive_val =  data_ret[4]& 0xff;
   derivitive_val_l =  data_ret[5]& 0xff;

   prop_val =  prop_val<<8  | prop_val_l;
   integral_val =  integral_val<<8  |  integral_val_l;
   derivitive_val =  derivitive_val <<8 | derivitive_val_l;

  SetCtrlVal(HtrMatCtrlPanel, HRTMATPNL_PROP,prop_val);
  SetCtrlVal(HtrMatCtrlPanel, HRTMATPNL_INTERGRAL,integral_val);
  SetCtrlVal(HtrMatCtrlPanel, HRTMATPNL_DERIVITIVE,derivitive_val);
}

int CVICALLBACK cb_quit (int panel, int control, int event,
		void *callbackData, int eventData1, int eventData2)
{
	switch (event)
	{
		case EVENT_COMMIT:
			SetCtrlAttribute(HtrMatCtrlPanel, HRTMATPNL_TIMER, ATTR_ENABLED, 0);   //Disable timer
			QuitUserInterface (0);
			break;
	}
	return 0;
}
int CVICALLBACK cbprop (int panel, int control, int event,
		void *callbackData, int eventData1, int eventData2)
{


	switch (event)
	{
		case EVENT_COMMIT:
			SendPIDValues();

			break;
	}
	return 0;
}

int CVICALLBACK cbintergral (int panel, int control, int event,
		void *callbackData, int eventData1, int eventData2)
{
	switch (event)
	{
		case EVENT_COMMIT:
			SendPIDValues();
			break;
	}
	return 0;
}

int CVICALLBACK cbderivitive (int panel, int control, int event,
		void *callbackData, int eventData1, int eventData2)
{
	switch (event)
	{
		case EVENT_COMMIT:
			SendPIDValues();
			break;
	}
	return 0;
}

int CVICALLBACK cbstorepid (int panel, int control, int event,
		void *callbackData, int eventData1, int eventData2)
{
char val1[20],data_ret[10],msg[256];
int stat,cmd,num_bytes;

	switch (event)
	{
		case EVENT_COMMIT:
		num_bytes = 1;
		cmd = 3;							//Command for writing PID values to EEPROM
		val1[0] = cmd;

		ComWrt(PORT, val1, num_bytes);

		data_ret[0]=0;							//Clear array

	//	stat = GetInQLen(PORT);
		ComRd(PORT, data_ret,1);					//Read ack
		if(data_ret[0]!=4){
			sprintf(msg, "ACK-ERROR");
			MessagePopup("USB: ",msg);
		}
			break;
	}
	return 0;
```

```
}

int CVICALLBACK cbtimer (int panel, int control, int event,
		void *callbackData, int eventData1, int eventData2)
{
char val1[20],data_ret[10],msg[256];
unsigned int stat,cmd,num_bytes, temp_val,max_power_val,temp_set_point_val;
unsigned int temp_set_point_val_l,temp_val_l,max_power_val_l;
double max_power_val_d,temp_val_d,temp_set_point_val_d;

	switch (event)
	{
		case EVENT_TIMER_TICK:

	while (GetInQLen (PORT)) {						//dump bytes which shouldn't be there
		if (rs232err < 0) ;
		ComRdByte(PORT);
	}

		num_bytes = 1;
		cmd = 5;							//Command to read PID values
		val1[0] = cmd;

		ComWrt(PORT, val1, num_bytes);

		data_ret[6]=0;							//Clear array

	//	stat = GetInQLen(PORT);
		ComRd(PORT, data_ret,7);					//Read data
		if(data_ret[6]!=4){
			sprintf(msg, "ACK-ERROR");
			MessagePopup("USB: ",msg);
		}


  temp_val =  (data_ret[0] <<8);
  temp_val_l =  data_ret[1] & 0xFF;

  max_power_val =  data_ret[2] <<8;
  max_power_val_l =  data_ret[3] & 0xFF;

  temp_set_point_val =  data_ret[4] <<8;
  temp_set_point_val_l =  data_ret[5] & 0xFF;

  temp_val = temp_val | temp_val_l;
  max_power_val =   max_power_val | max_power_val_l;
  temp_set_point_val =  temp_set_point_val | temp_set_point_val_l;


  temp_val_d= (temp_val*41.0)/1023;
  max_power_val_d=max_power_val/10.23;
  temp_set_point_val_d=(temp_set_point_val*41.0)/1023;


 SetCtrlVal(ReadEepromPanel, READEEPROM_TEMP,temp_val_d);
 SetCtrlVal(ReadEepromPanel, READEEPROM_MAX_POWER,max_power_val_d);
 SetCtrlVal(ReadEepromPanel, READEEPROM_TEMP_SET_POINT,temp_set_point_val_d);

			break;
	}
	return 0;
}

int CVICALLBACK cb_read (int panel, int control, int event,
		void *callbackData, int eventData1, int eventData2)
{
	switch (event)
	{
		case EVENT_COMMIT:
			DisplayPanel(ReadEepromPanel);
			SetCtrlAttribute (HtrMatCtrlPanel, HRTMATPNL_TIMER, ATTR_ENABLED, 1);	//Enable timer

			break;
	}
	return 0;
}

int CVICALLBACK cbreturn (int panel, int control, int event,
		void *callbackData, int eventData1, int eventData2)
{
	switch (event)
	{
		case EVENT_COMMIT:
			SetCtrlAttribute (HtrMatCtrlPanel, HRTMATPNL_TIMER, ATTR_ENABLED, 0);	//Disable timer
			HidePanel(ReadEepromPanel);
			break;
	}
	return 0;
}

int CVICALLBACK cb_readeeprom (int panel, int control, int event,
		void *callbackData, int eventData1, int eventData2)
{
char val1[20],data_ret[10],msg[256];
```

```
unsigned int stat,cmd,num_bytes,prop_val,integral_val,derivitive_val;
unsigned int prop_val_l,integral_val_l,derivitive_val_l;


	switch (event)
	{
		case EVENT_COMMIT:
		num_bytes = 1;
		cmd = 4;						//Command for reading PID values
		val1[0] = cmd;

		ComWrt(PORT, val1, num_bytes);

		data_ret[6]=0;					//Clear array

	//	stat = GetInQLen(PORT);
		ComRd(PORT, data_ret,7);				//Read data
		if(data_ret[6]!=4){
			sprintf(msg, "ACK-ERROR");
			MessagePopup("USB: ",msg);
		}
  prop_val =  data_ret[0] & 0xff ;
  prop_val_l =  data_ret[1] & 0xff;

  integral_val =  data_ret[2]& 0xff;
  integral_val_l =  data_ret[3]& 0xff;

  derivitive_val =  data_ret[4]& 0xff;
  derivitive_val_l =  data_ret[5]& 0xff;

  prop_val =  prop_val<<8  | prop_val_l;
  integral_val =  integral_val<<8  |  integral_val_l;
  derivitive_val =  derivitive_val <<8 | derivitive_val_l;

 SetCtrlVal(ReadEepromPanel, READEEPROM_PROP,prop_val);
 SetCtrlVal(ReadEepromPanel, READEEPROM_INTERGRAL,integral_val);
 SetCtrlVal(ReadEepromPanel, READEEPROM_DERIVITIVE,derivitive_val);

			break;
	}
	return 0;
}
```

The ‘Set point’ indicator relays the set-point temperature, as set by the hardware control, while the ‘Temperature’ indicator shows the actual temperature. When the ‘Chart’ button is pressed, a chart recorder-like display is shown, as depicted in Figure 7.

6. Performance

The typical performance of the system is also shown in Figure 7; warm-up time is less than 0.5 hour to ‘typical’ temperatures of ~35 degC and the cooling rate is comparable to heating rate.

In common with all ‘heating-only’ types of thermostats, the temperature control around ambient room temperature (or surround temperature) will be somewhat poor, unless heat losses are particularly high, and the system has been optimised for working temperatures at least 5 degrees above ambient. The response to load changes is reasonably fast (<2 mins). Upon application of a ‘cold’ load, the temperature drops and recovers within 60 secs; when the now-warmed load is removed, the temperature sensor ‘sees’ the ambient temperature (in this instance room temperature) and the temperature once again drops and recovers.

It is pointed out that the performance at a higher ambient temperature will be inevitably different to that shown here and that some adjustment of the PID gains may be required. Please contact the authors should this be required.

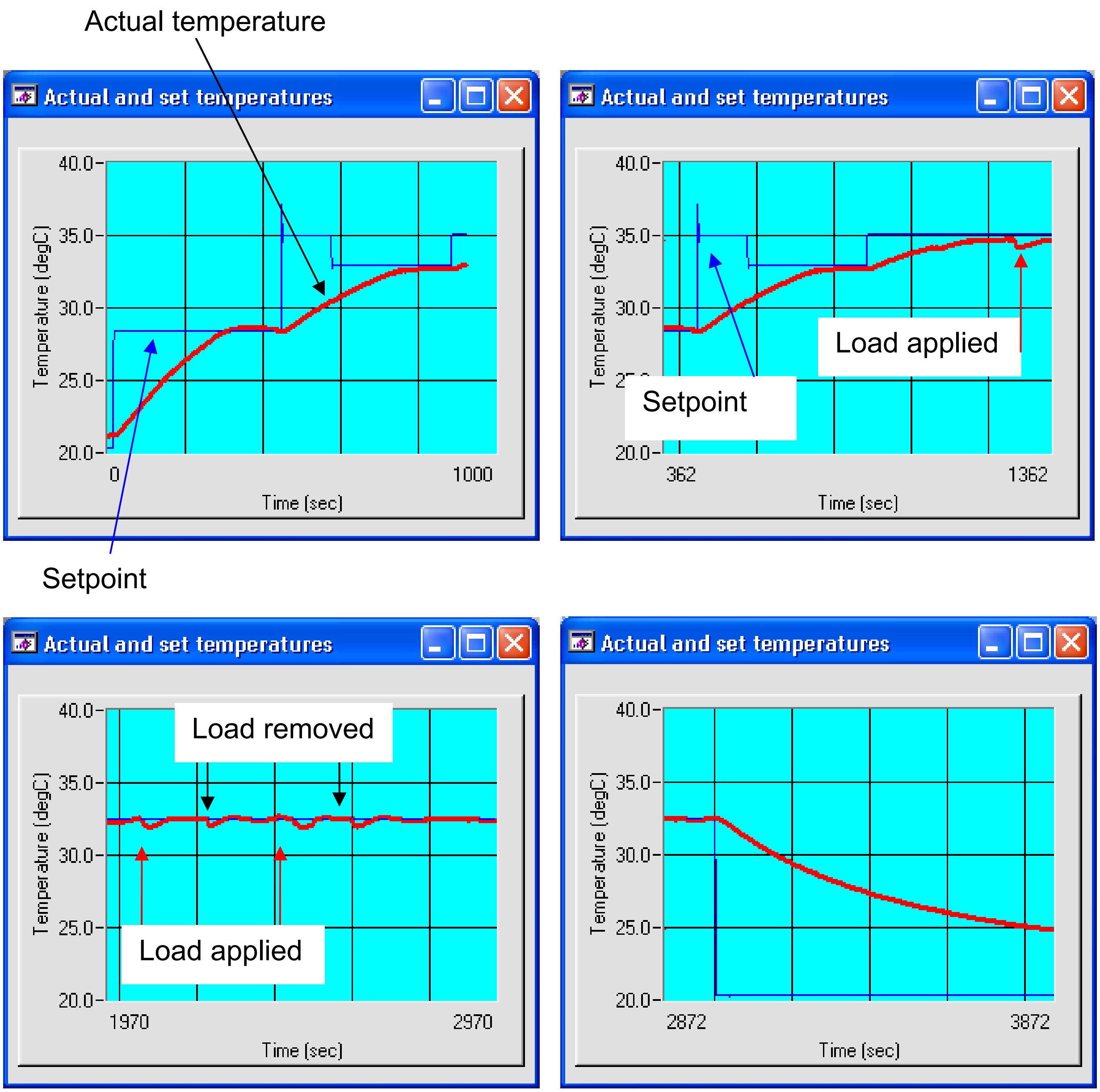


Figure 7: The chart recorder panels, which also show typical performance. The ‘load’ in this instance is a human hand placed on the insert.

All of the components used in this project are readily available form the following suppliers:

Onecall http://www.farnell.co.uk

RS Components Ltd http://rswww.com/

Future Technology Devices Internatoonal Ltd http://www.ftdichip.com

The electronic components used in the heated stage insert are listed below. However note that the prices refer to November 2010….since the UK economic situation is currently volatile (!) they should only be used as a guide.

Item	Supplier	Stock #	Part description	Qty	Cost
Heater mats	RS	245-512	Self-adhesive heatermat, 3.75W 12V 50 x 75mm	2 off	£ 29.28
Connecting cable	Onecall	131-003	Tyco Electronics T01-0599-B07-B, 7 way, 3 metres	1 off	£ 30.12
Temperature sensor	Onecall	179-8368	National Semiconductor LM62BIM3 - Temp Sensor, 3SOT23	1 off	£ 0.39
Enclosure	Onecall	301-243	Multicomp MB1, black	1 off	£ 1.82
Output connector	Onecall	130-886	Tyco Electronics, 7 way, panel mount, T01-0580-P07	1 off	£ 14.34
DC power input connector	Onecall	124-3248	Lumberg chassis socket, panel mount, 2.1 mm	1 off	£ 1.65
Power supply	Onecall	127-9473	Stontronics ROSA-151A-12UK 12V DC 1.25A	1 off	£ 14.62
Digital panel meter	Onecall	993-2844	Lascar - EMV 1025S-01 - 3.5 digit LCD Voltmeter 200 mV FSD	1 off	£ 16.57
Push button switch	RS	253-942	Honeywell 8N2021-Z, DPDT, Momentary	1 off	£ 5.95
Temperature set potentiometer	Onecall	151-7316	4k7 potentiometer with knob	1 off	£ 3.61
Power on LED	Onecall	104-5459	Vishay TLUR44HG, green LED 3mm	1 off	£ 0.192
Heating on LED	Onecall	104-5372	Vishay TLUR4400, red, LED 3mm	1 off	£ 0.143
Voltage regulator	Onecall	101-4073	Fairchild Semiconductors 78L05 5V regulator TO92	1 off	£ 0.194
Gain, offset amplifier	Onecall	955-9280	Linear technology, LT1013CN8, op amp, 8 pin DIP	1 off	£ 3.66
Voltage reference	Onecall	175-5114	Texas Instruments , LM4040C41ILP, 4.096 V, TO92	1 off	£ 0.356
MOSFET driver	Onecall	146-7958	2N7000 D26Z MOSFET, N, TO-92	1 off	£ 0.75
MOSFET power	Onecall	170-4021	IRF5210 MOSFETPBF, P, TO220	1 off	£ 2.03
USB controller	FTDI	DLP-245PB-G	USB / Microcontroller module	1 off	£ 22.20
Offset and gain presets	Onecall	935-3186	Bourns 3296W-1-103LF trimmer, 25 turn, 10 kΩ	2 off	£ 4.06
Set max power preset	Onecall	935-3240	Bourns 3296W-1-203LF trimmer, 25 turn, 20 kΩ	1 off	£ 2.03
Resistors	Onecall	various	MRS25 series 0.6W	13 off	£ 0.65
Input decoupling capacitor	Onecall	941-1887	Multicomp, MCFYU6104Z6, 50V, 100 nF	1 off	£ 0.066
Decoupling capacitors	Onecall	175-3978	Vishay Sprague, tantalum capacitor, 1 μF, 25 V	3 off	£ 2.94
Smoothing capacitor	Onecall	183-2428	Multicomp-MCTEA102M1EB , axial, 1000 μF, 25 V	1 off	£ 0.429
TOTAL					**£ 158.05**

7. Conclusion

A heated stage insert and temperature controller have been described, compatible with modern inverted microscopes. The inspiration for this project was provided by Dr Jacco Van Rheenen from the Hubrecht Institute in Holland (www.hubrecht.eu) who devised a simple and effective window chamber mount mount which allows microscopic resolution examination of rodent tumours. It is this chamber which fits inside the 14 mm hole in the stage plate (Figure 3 and below). The construction of the heated stage and the PIC-firmware PID controller may be found useful for other applications. Detailed SolidWorks drawings of the assembly are available on request. No printed circuit board design was developed for this as the wiring is extremely simple; the electronics were constructed on a prototype board.

This system was developed during November 2010 by J Prentice and B Vojnovic (mechanics) and by RG Newman and B Vojnovic (electronics, software), in consultation with R Muschel, T Tapmeier (biology). This note was written by B Vojnovic and RG Newman in December 2010 and updated in August 2011.

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