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REENTRY VEHICLE ADAPTIVE TELEMETRY

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Abstract

In RF telemetry (TM) the allowable RF bandwidth limits the amount of data in the telemetered data set. Typically the data set is less than ideal to accommodate all aspects of a test. In the case of diagnostic data, the compromise often leaves insufficient diagnostic data when problems occur. As a solution, intelligence was designed into a TM, allowing it to adapt to changing data requirements. To minimize the computational requirements for an intelligent TM, a fuzzy logic inference engine was developed. This inference engine was simulated on a PC and then loaded into a TM hardware package for final testing.

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REENTRY VEHICLE ADAPTIVE TELEMETRY

Introduction

In RF telemetry the allowable RF bandwidth limits the amount of data in the telemetered data set. Typically the data set is configured to focus on the expected events at the expense of the unexpected events, such as system malfunctions. This is particularly true of diagnostic data since the customer is only interested in their data, not system diagnostics.

System diagnostics are further compromised because full diagnostics require large amounts of data and the data is only interesting in the event of a malfunction. Therefore diagnostics are typically reduced to a bare minimum. Unfortunately if a malfunction does occur, diagnosis of the problem is complicated by the fact that only a small subset of the telemetered diagnostics actually addresses any given malfunction. Consequently there is never sufficient diagnostic data when problems occur.

Diagnostics are not the only data that is compromised due to RF bandwidth limits. Since it is not uncommon for data requirements to change during phases of the test, a fixed data set is a compromise among the data needed in all phases. In the past either a less-than-optimal data set was used to cover all phases of the test, or several TM packages were used to cover different phases of the test.

One solution to these compromises is to design intelligence into the TM so it can adapt to changing data needs. During various phases of a test, the data set could change to reflect the current needs. If a malfunction is suspected, the TM could focus the diagnostic data to better cover the problem area. By using an adaptive TM, critical data transmission is ensured and the data set is optimized, resulting in reduced data rate and bandwidth. This reduction in bandwidth increases the system's operating range and make it easier to use with encryption techniques.

In this report, the problem of insufficient diagnostic data is addressed. Fuzzy Logic is used to drive an inference engine that determines which diagnostic data should be transmitted and at what data rate, while keeping the bandwidth dedicated to diagnostics constant. The first section (THEORY) briefly covers the theory behind the algorithm. The second section (IMPLEMENTATION) outlines how the algorithm was implemented. The third section (SOFTWARE SIMULATION) covers the software simulation performed on a PC and points out the differences between the simulation software and the software used to implement the algorithm in the final TM hardware package. The fourth section (HARDWARE IMPLEMENTATION) describes the hardware and software used to test the adaptive TM on a TM hardware system. The fifth section (TEST RESULTS) describes the results of the hardware testing. The sixth section (CONCLUSIONS) summarizes the results and implications of the tests.

Theory

Figure 1 shows the a typical representation of boundaries between sets. In this example, a measurement is considered normal, too high, or too low. These boundaries are crisp, meaning a measurement is completely in one set and not at all in the other two sets. The transition from one set to another is abrupt. The only way to make these transition seem smoother is to break the sets into more subsets. However, the burden of computing a decision rapidly grows as the number of sets are increased.

Figure 1. Crisp boundaries for measurement values.

Fortunately, in the adaptive telemetry application, precise sets of values are not required. Exploiting this tolerance for imprecision allows the sets boundaries to be approximated, or made fuzzy. In Figure 2, the three sets shown in Figure 1 are drawn with new boundaries. These boundaries are not abrupt and overlap.

Figure 2. Fuzzy boundaries for measurement values.

The reasoning behind overlapping the set boundaries is to allow for a smoother transition from one set to another without increasing the number of sets. A slight increase in the number of sets dramatically increases the required computational power. The logic required to implement these overlapping sets is referred to as fuzzy logic. Using fuzzy logic to build a fuzzy inference engine allows more intelligence to be programmed in a particular hardware configuration since the number of sets remain low.

The data used by the adaptive telemetry is divided into two categories: major and minor data. Each major data has zero or more minor data within its data group. The major data is always transmitted, and the minor data is only transmitted if the major data is outside of its nominal specifications. Using this scheme, a representative sample (the major data) from each process being monitored is telemetered. When a major measurement is determined to be outside of normal parameters, its entire data group is telemetered, thus increasing the amount of telemetered data concerning the problem area. An example of this arrangement is shown in Table 1.

Temp 1	Volts 1	Temp 2
Voltage a	Current	
Voltage b	Temperature	
Voltage c		
Current a		
Current b		

Table 1. An example of the relationship between major and minor data. Here there are three major data measurements: Temp 1, Volt 1, and Temp 2. In this example major data Temp 1 is part of a data group that has five minor data: Voltage a, Voltage b, Voltage c, Current a, and Current b. Major data group Volt 1 has two minor data, and major data group Temp 2 consists of only one major measurement and no minor data.

The fuzzy inference engine makes several decisions based on the actual measurements of the major data. First it determines if the measurements are within normal parameters. If they are, all major data measurements are transmitted with equal sample rates. When a measurement is determined to be outside of its normal parameters, the frame size is adjusted to accommodate its minor data group. As the data moves further outside its normal parameters, the sample rate of the data group is increased relative to the other groups. Again the frame size is adjusted to accommodate the increased sampling rate.

The output of the inference engine is used to construct a list of measurement values to be transmitted. Each word in the list is 16 bits. Since the order and length of this list may change, it is necessary to tag each measurement with a code identifying each measurement.

Each 16 bit word consists of a tag code in the 6 most significant bits, and measurement data in the 10 least significant bits (Table 2). Using 6 bits for identification limits the number of unique measurements, both major and minor, in a list to 64. However, the total number of lists is not limited except, perhaps, by implementation restrictions. Limiting factors include the computational speed of the inference engine, and the number of slots allotted for in each major frame. The length of the list is determined by the number of data and the sample rate of the data.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TAG CODE						10 BIT MEASUREMENT DATA									

Table 2. Bit usage of each 16 bit data word transmitted.

Implementation

To take further advantage of the tolerance of imprecision, several restrictions are placed on the fuzzy inference engine. First, only 16 bit integer math is used. All values are scaled to take full advantage of the precision allowed for in 16 bits. Secondly, the inference engine was designed to run on the absolute value of the difference between the nominal value and the actual value. This allowed the fuzzy data set to be reduced to half at the expense of requiring that the remaining data set be symmetrical about some center value. This center value is considered the nominal value. Finally, the inference engine only accounts for the off nominal deviations. If the actual value is within a certain amount of the nominal value, no calculations are made. This amount of variance around the nominal value is referred to (in this report) as the minimum range. Figure 3 shows the simplified fuzzy data set implemented in this program. Here the nominal value is the vertical axis. The minimum range is the range from the vertical axis to the point "A." The point "B" is referred to as the maximum range. All values are predetermined to fall within the range of nominal to the point "B." As shown in Figure 3, all values beyond point "B" are clipped. Values beyond point "B" are still valid as far as the algorithm is concerned, but the values are treated the same as the value at "B."

Figure 3. Decision curve used in program.

In order to implement the idea of a data list, the single data list is duplicated into two lists in this implementation. Each list alternates between the active list and the inactive list. The active list contains the list of measurements currently being transmitted. Each time the routine *timer_tick* is called through a hardware interrupt, one measurement is updated and sent to the transmitter. When the last measurement in the list is read, the currently active list becomes inactive, and the currently inactive list becomes the active list. Once the lists change, the software invokes the fuzzy inference engine. This set of routines work in the background, computing a new list based on the data in the inactive list. The newly computed list is then written over the old, inactive list. The fuzzy inference engine then waits for the lists to change their active state again.

This dual list implementation results in a time lag in acting on measurements. When a measurement in the active list, say list #1, is read, it is not acted upon until the end of the active list (list #1) is reached. Then the data is used to generate a new list #1 while the other list (list #2) is being read and transmitted. This new list #1 remains inactive until the active list (list #2) is completed. When list #2 is completed, list #1 becomes active and the new data format is finally transmitted. This time lag affects only the data format and not the actual data, since the most current data is immediately transmitted.

Figure 4 shows a flow chart of the software developed to implement the inference engine used by the adaptive telemetry package. A description of each routine shown in the flow chart follows the flow chart.

Figure 4. Flowchart of software used in PC simulation.

list_extract

This routine is used both in the initialization and in the continuous loop. It removes the measurement data from the inactive list and places it into the measurement structure. This data is the most recent data gathered and is used to compute the next list of measurements to be transmitted.

off_nom

This routine is used both in the initialization and in the continuous loop. It computes the fuzzy value associated with how far off nominal the actual value is.

read_data

This routine is only used during system initialization. It reads from disk the data required to initialize the inference engine. This data includes the nominal value, the minimum and maximum expected deviations (points A and B in figure 3), and the size of the data group. It also reads in an initial value for each measurement. This value is inserted into both the active and the inactive list.

rel_freq

This routine is used both in the initialization and in the continuous loop. It calculates how often each measurement will appear in the list. It computes this by comparing the fuzzy values computed in *off_nom*. This routine also computes the length of the list. The length of the list is limited to a maximum of 256 items. An upper limit on the length of the list was set to reduce the time between reading a value that will cause a change in the structure of the list, and transmitting a new list.

set_up_screen

This routine is only used during system initialization. It also is only used in the simulation software. Its function is to initialize the computer screen to display simulated data.

sloper

This routine is used only in initialization. It computes the slope of the line from the minimum to the maximum deviation.

stuff_list

This routine is used both in the initialization and in the continuous loop. It creates the list based on the relative frequencies computed in *rel_freq*.

timer_tick

This routine is only used in the continuous loop. It is an interrupt handler, and for simulation purposes, it is called by the PC-DOS timer tick. In an actual application, the interrupt would be set by the transmitting hardware when data is needed for transmission. This routine reads the latest available data for the measurement pointed to in the active list, and transmits down the data. (In the simulation, the data is displayed on the screen in the appropriate area.) This routine also senses the end of the active list, and makes the currently inactive list, active. This switch is detected by the software and the new inactive list is used to compute the next active list.

Software simulation

The program developed to simulate the adaptive telemetry system on a PC is named "adaptm.c." It mimics a hardware application as closely as possible. A listing of the program

is given in Appendix A. This program and the PC it runs on proved to be a valuable platform for developing the adaptive TM algorithm. The program uses the PC-DOS 18ms timer tick as an interrupt to trigger data "transmission." The data is then "decommutated" in software. Transmission and decommutation amounts to creating and then independently deciphering the 6 bit identification code (see table 2) and printing the data on the screen in a predetermined place. The data itself is initialized from a disk file. In order that the data be varied during execution, the routine *main* contains code to accept data from the PC's keyboard in the background.

Hardware implementation

The program "adaptm.c" listed in Appendix A was modified to operate on the ASDACS (Advanced Stored Data Acquisition Control System) hardware package. The ASDACS package is a general purpose system used by the Telemetry Technology Development Department for instrumentation. The hardware configuration chosen to test the adaptive TM is as follows:

CPU	Intel 80C196KC
A/D converter	10 bit, 13.3uS
PCM Data output	NRZ-L
Main Memory	2MB

The data inputs were simulated using an array of 30 potentiometers and 24 switches. The potentiometers gave a continuously variable output from 0 to 5VDC, while the switches provided bilevel signals of 0 or 5VDC. These 54 signals were fed into a multiplexer/bilevel board controlled by the ASDACS. The variable output of the multiplexer/bilevel board was fed into the 10 bit A/D converter and the bilevel outputs of were read directly by the ASDACS.

Shown below in Figure 5 is a system level flowchart of the modified software. This shows the algorithmic flow, as well as the interrupt path taken when the transmission buffer is empty. Since the hardware PCM transmitter is double buffered, the hardware is transmitting one word while another is being loaded into the transmission buffer.

Figure 5 System level flowchart of the software used in the hardware application.

The modifications to "adaptm.c" listed in Appendix A are outlined below. The primary additions and modifications were made to accommodate the different platforms. The adaptive TM inference engine was not modified.

read_data

This routine was eliminated since the initialization data is stored in PROM and not on disk. The initialization of the variables was inserted in the variable initialization/definition section of the program. Here the data is manually transferred from PROM to RAM on startup.

set_up_screen

This routine was deleted since there is no video output.

timer_tick

This routine was replaced with the routine *PCM_buffer_empty*. This new routine is also interrupt driven. However it receives its interrupt signal from the PCM data transmission buffer when the buffer is empty. This routine then inserts the next data as determined by the data list.

Init_Internal_A2D

This routine was added to initialize the 10 bit A/D hardware.

Init_CPU

This routine was added to initialize the CPU hardware.

Init_PCM

This routine was added to initialize the PCM hardware.

Init_Interrupt

This routine was added to initialize the ASDACS hardware interrupts.

Main

This routine was modified to account for the new hardware and to remove the references to the PC keyboard entries. However, the algorithm for calling the adaptive TM routines were not changed.

Test results

To fully test the capabilities of the algorithm, 64 data inputs were needed. To accomplish this using the 54 outputs of the analog input array, 10 of the outputs were duplicated and used twice by the software. In software, 10 of the 64 possible measurements in the measurement list were remapped to 10 of the 54 inputs. All 20 of these duplicate signals (10 pairs) were bilevels and were used as minor data in various groups.

The 64 data inputs were grouped into 20 data groups. 18 of these groups had a variable input as their major data word, and 2 groups had a bilevel input as their major data word. The organization of the data groups is shown in Table 3. Also shown in Table 3 is the boundary conditions. A value is considered nominal if it fall within the limits of MIN. Once the value goes outside of the MIN limits, the inference engine considers the data to be off nominal and takes appropriate action. The action becomes more pronounced as the value approaches the limits of MAX. MAX is considered to be the farthest the value will ever be from nominal.

For example, if group 2 in Table 3 were a set of sensors on a human body with the major measurement being internal body temperature, a temperature value within the bounds of MIN would not cause alarm. However if the body temperature exceeds 100 degrees, the patient requires closer attention. When this occurs the software adds the other measurements in the group to the list of data being transmitted. As the major measurement approaches 110 degrees, the group 2 data is transmitted more frequently. In this example, values beyond 110 degrees are never expected. However, if the value was to exceed 110, the inference engine simply clips the value and treats the value as if it was 110.

GROUP #	MIN	MAX	MAJOR	MINOR
1	500+-10	500+-50	POT1	POT19,SW3,SW4
2	98+-2	98+-12	POT2	SW5,POT20,SW6,SW7,SW8
3	100+-10	100+-40	POT3	
4	128+-32	128+-110	POT4	SW9,SW10
5	110+-2	110+-5	POT5	POT21,SW11,POT22,SW12
6	900+-100	900+-300	POT6	SW13
7	75+-45	75+-60	POT7	
8	10+-5	10+-10	POT8	
9	512+-500	512+-999	POT9	SW14,POT23,SW15
10	180+-30	180+-35	POT10	POT25,SW16,SW17,SW18,SW19
11	645+-80	645+-140	POT11	SW20
12	120+-40	120+-80	POT12	SW21,SW22,SW23
13	100+-5	100+-100	POT13	SW24,SW3,SW4
14	80+-20	80+-50	POT14	
15	780+-130	780+-160	POT15	SW5,SW6
16	30+-20	30+-40	POT16	POT26,SW7,SW8,SW9
17	30+-30	30+-60	POT17	SW10
18	230+-30	230+-60	POT18	SW11,SW12,POT27,SW13,POT28
19	1+-10	1+-15	SW1	POT29,POT30
20	1022+-100	1022+-120	SW2	

Table 3. Data organization used in hardware testing.

Testing was performed at a relatively slow data rate to enable the observer to watch the reactions of the system. The system was tested by varying one or more of the analog inputs and observing the change in data and in data rate. Since the TM output was decommutated in real time, the effects could be seen on the video screen of the decommutating PC. Using this set up, we were able to exercise the algorithms ability to adapt to changing data requirements. The inputs were randomly varied in and out of the normal range while observing the system's reaction. Even a worse case scenario was performed with all data off normal to test the algorithm's conflict resolution capability. No problems were noted. Also the system was tested with all but one group off normal to ensure that the one normal group would still be sampled, if only occasionally.

Although the system was primarily tested at a data rate of 1kb/s, the system as configured operated successfully at data rates up to 100kb/s. At speeds greater than 100kb/s the ASDACS could no longer compute a new list before the old list was transmitted. Even though this speed far exceeds the typical diagnostic data channel, much higher speeds could be achieved by some simple changes. First of all, no attempts were made to streamline the software. It was written as a demonstration of an idea. Secondly the overhead associated with the demonstration software is unrealistic. A real TM system would have more than one data channel per frame. This system only has one data channel. This means all the overhead is dumped on one data channel rather than being spread out among many more channels. Even if this system were being used as one channel in a larger system, the 32 bits of the sync pattern and the SFID would not be present.

Conclusion

The testing demonstrated the ability of the algorithm to detect an out-of-normal condition and make an intelligent decision on what data is the most important. Due to the fuzzy logic the algorithm transitioned smoothly from one condition to the next. The algorithm had no problems handling more than one out-of-normal condition. Again, fuzzy logic assisted in the algorithm's conflict resolution capability.

If this system were used in an actual flight, its ability to focus the diagnostic data on the problem(s) at hand would greatly increase the value of the transmitted diagnostic data without increasing the required bandwidth.

Although this test focused on diagnostic data, the data could just as easily have been other flight data. This ability to fine tune the transmitted data could prove useful in focusing flight information on specific parts of the flight. This would increase the total amount of different flight data without increasing the required bandwidth.

Appendix A

The following is a program listing of the software used in the PC simulation of the adaptive TM.


```

int ticks_per_sample;
/* junk variables for printing to screen */

unsigned int i,j,k,l,m; /* temp variables */

unsigned int off_nom_num, nom_num, num_meas, crud_ptr[num_of_groups-1];
unsigned int list_ptr[num_of_groups-1];

unsigned char active_list[num_of_groups-1];
unsigned char list_change[num_of_groups-1];
unsigned char num_meas_in_group[num_of_groups - 1];
unsigned char curr_group;

unsigned int list_len[2*num_of_groups-1];
unsigned int list[2*num_of_groups-1][max_list_len];
unsigned int nom_list[64], off_nom_list[64];

unsigned int test_values[64];

struct measurement {int value;
                    unsigned int slope, fuzz, rf, blk_size;
                    int nominal, off_min, off_max;};

struct measurement meas[num_of_groups - 1][63];

/*
/*???|BLK|NOM|OFF|OFF|COMMENT ABOUT
/*???|SIZ|VALUE|MIN|MAX|MEASUREMENT
/*-----|---|-----|-----|-----|-----*/

/*****
/*
/* Name          timer_tick - Interrupt based on timer tick.
/*
/* Synopsis      (void) timer_tick(void)
/*
/* Description    This function decrements the variable tick_count by one each
/*                time it is called. This is called once each timer tick.
/*                There are 18.2 timer ticks per second.
/*
/*                This routine also reads the most current data and prints it
/*                out to the screen.
/*
/* Returns       void.
/*
/*
/*****
void interrupt far timer_tick(void)
{
    if (tick_count > 0) tick_count--;
    else
    {
        tick_count = ticks_per_sample - 1;
        tl = 2*curr_group + active_list[curr_group];

        if (list_ptr[curr_group] >= list_len[tl])
        { /* Reached end of list. Start new list */
            list_ptr[curr_group] = 0;
            active_list[curr_group] ^= 1; /* Change lists */
            list_change[curr_group] = 1; /* signal new list */
            tl = 2*curr_group + active_list[curr_group];
        }

        ti = list_ptr[curr_group];
        list[tl][ti] &= 0xFC00; /* clear lower 10 bits */
        list[tl][ti] |= (test_values[list[tl][ti] >> 10] & 0x03FF);

        last_loc = present_loc;
        present_loc = list[tl][list_ptr[curr_group]];
    }
}

```

```

    tk = (last_loc & 0xFC00) >> 10;
    ti = 2 + 2 * (tk / 8);
    tj = 5 + 10 * (tk - 8 * (tk/8));
    _settextposition(ti,tj);
    itoa((last_loc & 0x03FF),buff,10);

    if (!buff[1]) /* 1 digit to display */
    {
        buff[1] = buff[2] = 32;
        buff[3] = 0;
    }
    else
    if (!buff[2]) /* 2 digits to display */
    {
        buff[2] = 32;
        buff[3] = 0;
    }
    _setbkcolor(3L);
    _outtext(buff);

    tk = (present_loc & 0xFC00) >> 10;
    ti = 2 + 2 * (tk / 8);
    tj = 5 + 10 * (tk - 8 * (tk/8));
    _settextposition(ti,tj);
    itoa((present_loc & 0x03FF),buff,10);
    _setbkcolor(4L);
    _outtext(buff);
    list_ptr[curr_group]++;
}
}

/*****
/*
/* Name          set_up_screen - Set up the video screen with the format of
/*               the data.
/*
/* Synopsis      (void) set_up_screen(void)
/*
/* Description    This function clears the screen and enters slots for each
/*               data point.
/*
/* Returns       void.
/*
/*
/* *****/
void set_up_screen(void)
{
    _setbkcolor(2L);
    _settextcolor(0);
    _clearscreen(_GCLEARSCREEN);
    _setbkcolor(3L);
    for (i=0;i<8;i++)
    {
        for (j=0;j<8;j++)
        {
            sprintf(buff,"%2d:    ",i*8+j);
            _settextposition(i*2+2,j*10+2);
            _outtext(buff);
        }
    }
    _settextposition(19,1);
    _outtext("Current list:");
    _settextposition(20,1);
    _outtext("Current ptr:");
    _settextposition(21,1);
    _outtext("List length:");
    _settextposition(22,15);

```

```

    _outtext("Press 'F' to speed sampling. Press 'S' to slow sampling.");
    _setbkcolor(3L);
    _settextposition(24,1);
    _outtext("Enter meas to change and its new value:");
    _settextposition(25,15);
    _outtext("Press 'SPACE' between meas and value, and 'SPACE' after value");
}

/*****
/*
/* Name          list_extract - Transfers data from current list to meas.
/*
/*
/* Synopsis      (void) list_extract(void)
/*
/* Description    This function reads the latest data from the list and
/*                inserts the data into the measurement structure. Since the
/*                data is operated on only while in the measurement structure,
/*                this is required.
/*
/* Returns       void.
/*
/*
*****/
void list_extract(void)
{
    j = active_list[curr_group] - 1; /* assign old list to j */
    j += 2*curr_group; /* j now describes correct list */

    for (i=0; i<list_len[j]; i++)
    {
        meas[curr_group][list[j][i] & 0xFC00 >> 10].value = list[j][i] & 0x03FF;
    }
}

/*****
/*
/* Name          read_data - Routine to gather data.
/*
/*
/* Synopsis      (void) read_data(void)
/*
/* Description    This function reads a file named fuzzytm.dat. The values
/*                read are expected to be unsigned integer values with 10 bits
/*                of resolution. These values are treated as measurement
/*                values for testing of the program. They are inserted into
/*                both measurement lists.
/*
/* Returns       void.
/*
/*
*****/
void read_data(void)
{
    FILE *file_handle;
    char buff[80],*stopstring;

    file_handle = fopen("fuzzytm.dat","rt");
    if (file_handle == NULL)
    {
        printf("File 'fuzzytm.dat' could not be opened.\n");
        exit(1);
    }

    j = 0;
    num_meas = 0;

```

```

while (!feof(file_handle))
{
    fgets(buff,80,file_handle);

    i = (j << 10) + (int)strtol(buff,&stopstring,10);

    test_values[j] = list[0][j] = list[1][j] = i;

    meas[curr_group][j].blk_size =
        (int)strtol((stopstring+1),&stopstring,10);
    meas[curr_group][j].nominal =
        (int)strtol((stopstring+1),&stopstring,10);
    meas[curr_group][j].off_min =
        (int)strtol((stopstring+1),&stopstring,10);
    meas[curr_group][j].off_max =
        (int)strtol((stopstring+1),&stopstring,10);
    if (meas[curr_group][j-1].blk_size > 0) num_meas++;
}
num_meas_in_group[curr_group] = (unsigned char)j;
list_len[2*curr_group] = list_len[2*curr_group+1] = j;

fclose(file_handle);
}

/*****
/*
/* Name          sloper -- Routine calculates the slope of the line from
/*                off-min to off-max.
/*
/*
/* Synopsis      (void) sloper(void)
/*
/* Description   This function computes the slope of the lines used to
/*                determine the off nominal value. It nominalizes the slope
/*                to 30000 in order to maximize the precision of integer math.
/*                If the resulting slope is less than 2, a value of 2 is used.
/*
/* Returns       void.
/*
/*
/*
*****/
void sloper(void)
{
    i = 0;

    while(i < num_meas_in_group[curr_group])
    {
        meas[curr_group][i].slope = 30000/(abs(meas[curr_group][i].off_max -
                                                meas[curr_group][i].off_min));
        if (meas[curr_group][i].slope < 2) meas[curr_group][i].slope = 2;
        i += meas[curr_group][i].blk_size;
    }
}

/*****
/*
/* Name          off_nom -- Routine calculates the off-nominal value of the
/*                variable.
/*
/*
/* Synopsis      (int) off_nom(
/*                int meas_num - index of the measurement in
/*                question.
/*
/*
*****/

```

```

/* Description  This function computes the fuzzy value associated with being*/
/*              off nominal. It uses the global variables describing the */
/*              off-nominal function associated with each measurement. For */
/*              speed concerns, the only function allowed is a simple line */
/*              from the minimum value to the maximum value of what is */
/*              considered off-nominal. Also, the function is assumed to */
/*              be symmetric about the nominal point, and thus the absolute */
/*              value of the difference between nominal and the current */
/*              value is used. */
/*              */
/*              Although it is customary to use values from 0 to 1 as the */
/*              output of the fuzzy computation, this routine returns an */
/*              integer value from 10 to 100. This allows for the use of the*/
/*              faster integer arithmetic. */
/*              */
/* Returns      The integer value returned is the fuzzy measurement of how */
/*              far off nominal the measurement is. The value ranges from */
/*              10 (within normal parameters) and 100 (considered completely*/
/*              abnormal). */
/*              */
/*              */
/*              */
/*****
void off_nom(void)
{
    j = off_nom_num = nom_num = 0;
    while(j < num_meas_in_group[curr_group])
    {
        i = abs(meas[curr_group][j].value - meas[curr_group][j].nominal);

        if (i <= meas[curr_group][j].off_min)
        {
            meas[curr_group][j].fuzz = 10;
            nom_list[nom_num++] = j;
        }
        else
        if (i >= meas[curr_group][j].off_max)
        {
            meas[curr_group][j].fuzz = 10 + max_priority_range;
            off_nom_list[off_nom_num++] = j;
        }
        else
        {
            i -= meas[curr_group][j].off_min;
            i *= meas[curr_group][j].slope;
            i /= max_priority_divisor;
            meas[curr_group][j].fuzz = i + 10;
            off_nom_list[off_nom_num++] = j;
        }
        j += meas[curr_group][j].blk_size;
    }
}

/*****
/*
/* Name          rel_freq -- Routine calculates the relative frequency of */
/*              each measurement, as well as the length of the */
/*              measurement list. */
/*              */
/* Synopsis      (void) rel_freq(void) */
/*              */
/* Description   This function computes the relative frequency by summing the*/
/*              fuzzy off-normal measurement values, and then dividing each */
/*              off-normal measurement into the sum. This value is used to */
/*              determine how often the measurement will occur in the list */
/*              of measurements. For example, a value of 7 would indicate */
/*              this measurement occurs every 7 samples. */

```

```

/*
/*          This function also computes the length of the measurement
/*          list by dividing the sum of the measurement priorities by 2.*/
/*
/* Returns    void.
/*
/*
/*****
void rel_freq(void)
{
    i = j = 0;

    while(i < num_meas_in_group[curr_group])
    {
        if (meas[curr_group][i].fuzz > 10)
        {
            j += (meas[curr_group][i].fuzz * meas[curr_group][i].blk_size);
        }
        else
        {
            j += 10;
        }
        i += meas[curr_group][i].blk_size;
    }

    i = 0;
    while(i < num_meas_in_group[curr_group])
    {
        meas[curr_group][i].rf = (j*10) / meas[curr_group][i].fuzz;
        i += meas[curr_group][i].blk_size;
    }

    if (j/2 > max_list_len)
        list_len[2*curr_group + (active_list[curr_group] ^ 1)] = max_list_len;
    else
        list_len[2*curr_group + (active_list[curr_group] ^ 1)] = j / 2;
}

/*****
/*
/* Name      stuff_list -- This routine inserts the information into the
/*          data list.
/*
/* Synopsis  (void) stuff_list(void)
/*
/* Description Using the relative frequency (RF) of the data, "stuff_list"
/*          inserts the data into the list, beginning with the lowest
/*          relative frequency (highest priority data). The RF is used
/*          to determine how often the measurement is inserted. Once
/*          the lowest RF data is inserted, the next lowest is inserted.
/*          If the desired slot is occupied, the next available is taken.
/*
/* Returns    void.
/*
/*
/*****
void stuff_list(void)
{
    m = 2*curr_group+active_list[curr_group] ^ 1; /* use the idle list */

    for (i = 0; i < max_list_len; i++) list[m][i] = 0; /* clear list */

    /* Sort the off-nominal list so smallest RF is first. */
    for (i = 0; i < off_nom_num; i++)
    {
        for (j = 1; j < off_nom_num; j++)
        {
            if (meas[curr_group][off_nom_list[j]].rf <
                meas[curr_group][off_nom_list[i]].rf)

```



```

    {
        l = off_nom_list[i];
        off_nom_list[i] = off_nom_list[j];
        off_nom_list[j] = l ;
    }
}

/* First, stuff in the off nominal measurements and their blocks */

for (i = 0; i < off_nom_num; i++)
{
    for (j=0; j<10*list_len[m]; j+=meas[curr_group][off_nom_list[i]].rf)
    {
        l = j/10;
        for (k = 0; k < meas[curr_group][off_nom_list[i]].blk_size; k++)
        {
            if (!(list[m][l] & 0x00FF))
            { /* slot is open. Insert this item into list here. */
                list[m][l++] = 1 + ((off_nom_list[i] + k) << 10);
            }
            else
            { /* slot is NOT open. Look for next available space. */
                if(++l >= list_len[m])
                { /* At the end of the list. No more in this block can fit. */
                    break;
                }
            }
            else
            { /* Let's see if this block is open. */
                k--;
                continue;
            }
        }
    }
}

/* Now fill list with the nominal measurements. */
l = 0;
while (l < list_len[m])
{
    i = 0;
    do /* use do..while to ensure at least one pass in case nom_num=0 */
    {
        if (!(list[m][l] & 0x00FF))
        { /* slot is open. Insert this item into list here. */
            list[m][l++] = 1 + (nom_list[i] << 10);
            i++;
        }
        else
        { /* slot is NOT open. Look for next available space. */
            if(++l >= list_len[m])
            { /* At the end of the list. No more in this block can fit. */
                break;
            }
        }
        else
        { /* Let's see if this block is open. */
            continue;
        }
    }
} while (i < nom_num);
}

/*****
/*
/* Name          main -- Primary routine of program.
*/
*****/

```

```

/*                                                                    */
/*                                                                    */
/* Synopsis      (void) main(void)                                     */
/*                                                                    */
/* Description   This function tests the validity of the fuzzy TM idea. */
/*                                                                    */
/* Returns      Void.                                                 */
/*                                                                    */
/*****
void main(void)
{
    int val_int, sig_int, sig_val, the_ptr, char_position;
    char val_char[10], sig_char[10], inp_char;

    the_ptr = sig_val = present_loc = curr_group = 0;
    val_int = 1;

    char_position = 42;
    screen = (int far *)0xb8000000;
    screen_off = 0;

    for (i=0;i<num_of_groups;i++)
    {
        active_list[i] = 0;
        list_ptr[i] = 0;
        list_change[i] = 0;
    }

    val_char[0] = 0;
    sig_char[0] = 0;

    ticks_per_sample = 1; /* default number of ticks per sample */

    read_data(); /* for testing, read initial data from disk */

    set_up_screen();

    old_timer = _dos_getvect(0x1C); /* save current timer tick */

    sloper();
    list_extract();
    off_nom();
    rel_freq();
    stuff_list();

    _dos_setvect(0x1C,timer_tick);

    while (val_int)
    {
        if (list_change[curr_group])
        {
            list_extract();
            off_nom();
            rel_freq();
            stuff_list();

            list_change[curr_group] = 0;

            itoa(active_list[curr_group],buff1,10);
            outp(0x21,1);
            _settextposition(19,15);
            _outtext(buff1);
            outp(0x21,0);

            itoa(list_len[2*curr_group + active_list[curr_group] ],buff1,10);
            if (!buff1[2])

```

```

    {
        buff1[3] = 0;
        buff1[2] = 32;
    }
    outp(0x21,1);
    _settextposition(21,15);
    _outtext(buff1);
    outp(0x21,0);
}

itoa(list_ptr[curr_group],buff1,10);
if (!buff1[2])
{
    buff1[3] = 0;
    buff1[2] = 32;
}
outp(0x21,1);
_settextposition(20,15);
_outtext(buff1);
outp(0x21,0);

if (kbhit())
{
    inp_char = (char)getch();
    if (inp_char == 'p' || inp_char == 'P')
    {
        _dos_setvect(0x1C,old_timer);
    }
    else
    if (inp_char == 'g' || inp_char == 'G')
    {
        _dos_setvect(0x1C,timer_tick);
    }
    else
    if (inp_char == 's' || inp_char == 'S')
    {
        ticks_per_sample++;
    }
    else
    if (inp_char == 'f' || inp_char == 'F')
    {
        if (ticks_per_sample > 1) ticks_per_sample--;
    }
    else
    {
        _setbkcolor(3L);
        if (!sig_val)
        {
            sig_char[the_ptr] = inp_char;
            sprintf(buff1,"%c",sig_char[the_ptr]);

            outp(0x21,1);
            _settextposition(24,char_position++);
            _outtext(buff1);
            outp(0x21,0);

            if (sig_char[the_ptr] == 32)
            {
                sig_char[the_ptr] = 0;
                sig_int = atoi(sig_char);
                sig_val = 1;
                the_ptr = 0;
            }
            else the_ptr++;
        }
    }
    else
    {
        val_char[the_ptr] = inp_char;
    }
}

```

```

    sprintf(buff1,"%c",val_char[the_ptr]);

    outp(0x21,1);
    _settextposition(24,char_position++);
    _outtext(buff1);
    outp(0x21,0);

    if (val_char[the_ptr] == 32)
    {
        val_char[the_ptr] = 0;
        val_int = atoi(val_char);
        sig_val = 0;
        the_ptr = 0;
        test_values[sig_int] = val_int;
        char_position = 42;
        _setbkcolor(2L);

        outp(0x21,1);
        _settextposition(24,char_position++);
        _outtext("        ");
        outp(0x21,0);

        char_position = 42;
    }
    else the_ptr++;
}
}
}
}
_dos_setvect(0x1C,old_timer);
}

```

Appendix B

The following is a program listing of software used to drive the ASDACS hardware package.

```

/*****
/*****
/****
/**** Fuzzy TM controller Version 2.0
/**** =====
/**** File: adaptm.c
/**** Author: Ronald E. Kidner
/**** Date: 06/24/93
/****
/****
/**** Compiled for the 80C196KC
/**** Sandia National Labs
/**** Albuquerque, NM
/****
/*****
/*****

#pragma ccb(0xEF) /* set the chip configuration register */
#pragma interrupt (PCM_buffer_empty = 7) /* External Interrupt */

/*****
/* Include Files
/*****

#include <80c196.h>
#include "sd_addr.h"
#include <stdio.h>

/*****
/* Define Definitions
/*****

#define max_priority_range 30 /* user defined max difference from lowest */
/* computed priority to highest priority */

#define max_priority_divisor 30000/max_priority_range

#define max_list_len 256 /* max possible len of list */

#define num_meas_in_group 64 /* total meas in the group */

#define num_of_groups 2 /* number of groups of data. Each group */
/* occupies one location in major frame */
/* Each group requires two slots, so that */
/* for 1 group, enter 2 here. For 3 groups*/
/* enter 6 here. */

#define value 0
#define slope 1
#define fuzz 2
#define rf 3
#define blk_size 4
#define nominal 5
#define off_min 6
#define off_max 7

unsigned int BILEVEL1; /* Location of bilevel buffer #1 (16 bit) */
#pragma locate (BILEVEL1 = 0xFF0C)

unsigned int BILEVEL2; /* Location of bilevel buffer #2 (8 bit) */
#pragma locate (BILEVEL2 = 0xFF0A)

unsigned int MUXSET; /* Location of mux control channel */
#pragma locate (MUXSET = 0xFF08)

/*****
/* External Functions
/*****
/*****

```

```

/* Internal Functions */
/*****
void Init_PCM(void);
void Init_Interruption(char,char,char,char,char);
void print_PCM(unsigned int);
void Init_CPU(void);
void Init_Internal_A2D(char);
void list_extract(void);
void off_nom(void);
void read_data(void);
void rel_freq(void);
void set_up_screen(void);
void sloper(void);
void stuff_list(void);
void PCM_buffer_empty(void);
void initialize_list(void);

*****/

/* Internal Variables */
/*****
unsigned int temp,i,j,k,l,m,n,o; /* temp variables */

unsigned int off_nom_num, nom_num;
unsigned int list_ptr, mem_ptr;

unsigned int active_list;
unsigned int list_change;
unsigned int frame_position;

unsigned int list_len[2];
unsigned int nom_list[64], off_nom_list[64];

/* initialize list */
void initialize_list(void)
{
    MMP_LD_HI = 0; /* use first 64k of main memory */
    MMP_LD_LO = 0;
    MMP_COUNT_ENABLE; /* for this routine, MMP does auto increment */

    MMP = 500; /* initial value of MAIN 1 */
    MMP = 0;
    MMP = 0;
    MMP = 0;
    MMP = 4; /* block size */
    MMP = 500; /* nominal value */
    MMP = 10; /* off nominal minimum */
    MMP = 50; /* off nominal maximum */

    /* now fill in the zeros representing the sub data */
    for (i = 0; i < 3 * 8; i++) MMP = 0;

    MMP = 98; /* initial value of MAIN 2 */
    MMP = 0;
    MMP = 0;
    MMP = 0;
    MMP = 6; /* block size */
    MMP = 98; /* nominal value */
    MMP = 2; /* off nominal minimum */
    MMP = 12; /* off nominal maximum */

    /* now fill in the zeros representing the sub data */
    for (i = 0; i < 5 * 8; i++) MMP = 0;

    MMP = 100; /* initial value of MAIN 3 */
    MMP = 0;
    MMP = 0;
    MMP = 0;

```

```

MMP = 1;          /* block size          */
MMP = 100;        /* nominal value          */
MMP = 10;         /* off nominal minimum    */
MMP = 40;         /* off nominal maximum    */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 0 * 8; i++) MMP = 0;

MMP = 128;        /* initial value of MAIN 4 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 3;          /* block size          */
MMP = 128;        /* nominal value          */
MMP = 32;         /* off nominal minimum    */
MMP = 110;        /* off nominal maximum    */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 2 * 8; i++) MMP = 0;

MMP = 110;        /* initial value of MAIN 5 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 5;          /* block size          */
MMP = 110;        /* nominal value          */
MMP = 2;          /* off nominal minimum    */
MMP = 5;          /* off nominal maximum    */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 4 * 8; i++) MMP = 0;

MMP = 900;        /* initial value of MAIN 6 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 2;          /* block size          */
MMP = 900;        /* nominal value          */
MMP = 100;        /* off nominal minimum    */
MMP = 300;        /* off nominal maximum    */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 1 * 8; i++) MMP = 0;

MMP = 75;         /* initial value of MAIN 7 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 1;          /* block size          */
MMP = 75;         /* nominal value          */
MMP = 45;         /* off nominal minimum    */
MMP = 60;         /* off nominal maximum    */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 0 * 8; i++) MMP = 0;

MMP = 10;         /* initial value of MAIN 8 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 1;          /* block size          */
MMP = 10;         /* nominal value          */
MMP = 5;          /* off nominal minimum    */
MMP = 10;         /* off nominal maximum    */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 0 * 8; i++) MMP = 0;

```



```

MMP = 512;      /* initial value of MAIN 9 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 4;      /* block size */
MMP = 512;    /* nominal value */
MMP = 500;    /* off nominal minimum */
MMP = 999;    /* off nominal maximum */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 3 * 8; i++) MMP = 0;

MMP = 180;    /* initial value of MAIN 10 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 6;      /* block size */
MMP = 180;    /* nominal value */
MMP = 30;     /* off nominal minimum */
MMP = 35;     /* off nominal maximum */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 5 * 8; i++) MMP = 0;

MMP = 645;    /* initial value of MAIN 11 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 2;      /* block size */
MMP = 645;    /* nominal value */
MMP = 80;     /* off nominal minimum */
MMP = 140;    /* off nominal maximum */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 1 * 8; i++) MMP = 0;

MMP = 120;    /* initial value of MAIN 12 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 4;      /* block size */
MMP = 120;    /* nominal value */
MMP = 40;     /* off nominal minimum */
MMP = 50;     /* off nominal maximum */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 3 * 8; i++) MMP = 0;

MMP = 100;    /* initial value of MAIN 13 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 4;      /* block size */
MMP = 100;    /* nominal value */
MMP = 5;      /* off nominal minimum */
MMP = 100;    /* off nominal maximum */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 3 * 8; i++) MMP = 0;

MMP = 80;     /* initial value of MAIN 14 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 1;      /* block size */
MMP = 80;     /* nominal value */
MMP = 20;     /* off nominal minimum */
MMP = 50;     /* off nominal maximum */

```

```

/* now fill in the zeros representing the sub data */
for (i = 0; i < 0 * 8; i++) MMP = 0;

MMP = 780;          /* initial value of MAIN 15 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 3;           /* block size */
MMP = 780;         /* nominal value */
MMP = 130;         /* off nominal minimum */
MMP = 160;         /* off nominal maximum */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 2 * 8; i++) MMP = 0;

MMP = 30;          /* initial value of MAIN 16 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 5;           /* block size */
MMP = 30;          /* nominal value */
MMP = 20;          /* off nominal minimum */
MMP = 40;          /* off nominal maximum */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 4 * 8; i++) MMP = 0;

MMP = 30;          /* initial value of MAIN 17 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 2;           /* block size */
MMP = 30;          /* nominal value */
MMP = 30;          /* off nominal minimum */
MMP = 60;          /* off nominal maximum */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 1 * 8; i++) MMP = 0;

MMP = 230;         /* initial value of MAIN 18 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 6;           /* block size */
MMP = 230;         /* nominal value */
MMP = 30;          /* off nominal minimum */
MMP = 60;          /* off nominal maximum */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 5 * 8; i++) MMP = 0;

MMP = 1;           /* initial value of MAIN 19 */
MMP = 0;
MMP = 0;
MMP = 0;
MMP = 3;           /* block size */
MMP = 1;           /* nominal value */
MMP = 10;          /* off nominal minimum */
MMP = 15;          /* off nominal maximum */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 2 * 8; i++) MMP = 0;

MMP = 1022;        /* initial value of MAIN 20 */
MMP = 0;
MMP = 0;
MMP = 0;

```

```

MMP = 1;          /* block size          */
MMP = 1022;       /* nominal value          */
MMP = 100;        /* off nominal minimum    */
MMP = 120;        /* off nominal maximum    */

/* now fill in the zeros representing the sub data */
for (i = 0; i < 0 * 8; i++) MMP = 0;

MMP_COUNT_DISABLE; /* from now on, MMP does not auto increment */
}

/*****
/*
/* Name          PCM_buffer_empty - ISR for the PCM data buffer.
/*
/* Synopsis      (void) PCM_buffer_empty(void)
/*
/* Description    This function responds the the external interrupt. If it is
/*                determined to be caused by the PCM empty (RCO falling) a new
/*                data word is written to the PCM buffer.
/*
/* Returns       void.
/*
*****/
void PCM_buffer_empty(void)
{
/* For simplicity, I make the assumption that the only Ext inter is PCM */
switch (frame_position)
{
case 0: /* First word of frame: 0xFAF3 */
frame_position = 1;
SHIFT_REG = 0xFAF3; /* output word to the shift register */
break;

case 1: /* Second word of frame: 0x2000 */
frame_position = 2;
SHIFT_REG = 0x2000; /* output word to the shift register */
break;

case 2: /* Third and final word of frame: data */
frame_position = 0;

MMP_LD_LO = (0x400 << active_list) + list_ptr++;
temp = MMP & 0xFC00; /* clear lower 10 bits */

switch (temp >> 10)
{
case 0:
ad_command = 8; /* 10 bit, channel 0 */
while (ad_result_lo & 0x08); /* wait until A/D is done */
temp |= (((unsigned int)(ad_result_hi) << 8)
+ ad_result_lo) >> 6) & 0x03FF;
break;

case 1:
ad_command = 8; /* 10 bit, channel 0 */
while (ad_result_lo & 0x08); /* wait until A/D is done */
temp |= (((unsigned int)(ad_result_hi) << 8)
+ ad_result_lo) >> 6) & 0x03FF;
break;

case 2:
temp |= ((B1LEVEL1 & 0x0004) > 0) * 1023;
break;
}
}
}

```

```

case 3:
    temp |= ((B1LEVEL1 & 0x0008) > 0) * 1023;
    break;

case 4:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
    break;

case 5:
    temp |= ((B1LEVEL1 & 0x0010) > 0) * 1023;
    break;

case 6:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
    break;

case 7:
    temp |= ((B1LEVEL1 & 0x0020) > 0) * 1023;
    break;

case 8:
    temp |= ((B1LEVEL1 & 0x0040) > 0) * 1023;
    break;

case 9:
    temp |= ((B1LEVEL1 & 0x0080) > 0) * 1023;
    break;

case 10:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
    break;

case 11:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
    break;

case 12:
    temp |= ((B1LEVEL1 & 0x0100) > 0) * 1023;
    break;

case 13:
    temp |= ((B1LEVEL1 & 0x0200) > 0) * 1023;
    break;

case 14:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
    break;

case 15:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;

```

```

break;

case 16:
    temp |= ((B1LEVEL1 & 0x0400) > 0) * 1023;
break;

case 17:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
break;

case 18:
    temp |= ((B1LEVEL1 & 0x0800) > 0) * 1023;
break;

case 19:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
break;

case 20:
    temp |= ((B1LEVEL1 & 0x1000) > 0) * 1023;
break;

case 21:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
break;

case 22:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
break;

case 23:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
break;

case 24:
    temp |= ((B1LEVEL1 & 0x2000) > 0) * 1023;
break;

case 25:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo >> 6) & 0x03FF;
break;

case 26:
    temp |= ((B1LEVEL1 & 0x4000) > 0) * 1023;
break;

case 27:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)

```

```

        + ad_result_lo) >> 6) & 0x03FF;
break;

case 28:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo) >> 6) & 0x03FF;
break;

case 29:
    temp |= ((B1LEVEL1 & 0x8000) > 0) * 1023;
break;

case 30:
    temp |= ((B1LEVEL2 & 0x0001) > 0) * 1023;
break;

case 31:
    temp |= ((B1LEVEL2 & 0x0002) > 0) * 1023;
break;

case 32:
    temp |= ((B1LEVEL2 & 0x0004) > 0) * 1023;
break;

case 33:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo) >> 6) & 0x03FF;
break;

case 34:
    temp |= ((B1LEVEL2 & 0x0008) > 0) * 1023;
break;

case 35:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo) >> 6) & 0x03FF;
break;

case 36:
    temp |= ((B1LEVEL2 & 0x0010) > 0) * 1023;
break;

case 37:
    temp |= ((B1LEVEL2 & 0x0020) > 0) * 1023;
break;

case 38:
    temp |= ((B1LEVEL2 & 0x0040) > 0) * 1023;
break;

case 39:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo) >> 6) & 0x03FF;
break;

case 40:
    temp |= ((B1LEVEL2 & 0x0080) > 0) * 1023;
break;

case 41:

```

```

    temp |= ((B1LEVEL1 & 0x0004) > 0) * 1023;
    break;

case 42:
    temp |= ((B1LEVEL1 & 0x0008) > 0) * 1023;
    break;

case 43:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo) >> 6) & 0x03FF;
    break;

case 44:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo) >> 6) & 0x03FF;
    break;

case 45:
    temp |= ((B1LEVEL1 & 0x0010) > 0) * 1023;
    break;

case 46:
    temp |= ((B1LEVEL1 & 0x0020) > 0) * 1023;
    break;

case 47:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo) >> 6) & 0x03FF;
    break;

case 48:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo) >> 6) & 0x03FF;
    break;

case 49:
    temp |= ((B1LEVEL1 & 0x0040) > 0) * 1023;
    break;

case 50:
    temp |= ((B1LEVEL1 & 0x0080) > 0) * 1023;
    break;

case 51:
    temp |= ((B1LEVEL1 & 0x0100) > 0) * 1023;
    break;

case 52:
    ad_command = 8; /* 10 bit, channel 0 */
    while (ad_result_lo & 0x08); /* wait until A/D is done */
    temp |= (((unsigned int)(ad_result_hi) << 8)
        + ad_result_lo) >> 6) & 0x03FF;
    break;

case 53:
    temp |= ((B1LEVEL1 & 0x0200) > 0) * 1023;
    break;

case 54:
    ad_command = 8; /* 10 bit, channel 0 */

```

```

        while (ad_result_lo & 0x08); /* wait until A/D is done */
        temp |= (((unsigned int)(ad_result_hi) << 8)
            + ad_result_lo >> 6) & 0x03FF;
        break;

    case 55:
        temp |= ((BILEVEL1 & 0x0400) > 0) * 1023;
        break;

    case 56:
        temp |= ((BILEVEL1 & 0x0800) > 0) * 1023;
        break;

    case 57:
        ad_command = 8; /* 10 bit, channel 0 */
        while (ad_result_lo & 0x08); /* wait until A/D is done */
        temp |= (((unsigned int)(ad_result_hi) << 8)
            + ad_result_lo >> 6) & 0x03FF;
        break;

    case 58:
        temp |= ((BILEVEL1 & 0x1000) > 0) * 1023;
        break;

    case 59:
        ad_command = 8; /* 10 bit, channel 0 */
        while (ad_result_lo & 0x08); /* wait until A/D is done */
        temp |= (((unsigned int)(ad_result_hi) << 8)
            + ad_result_lo >> 6) & 0x03FF;
        break;

    case 60:
        temp |= ((BILEVEL1 & 0x0001) > 0) * 1023;
        break;

    case 61:
        ad_command = 8; /* 10 bit, channel 0 */
        while (ad_result_lo & 0x08); /* wait until A/D is done */
        temp |= (((unsigned int)(ad_result_hi) << 8)
            + ad_result_lo >> 6) & 0x03FF;
        break;

    case 62:
        ad_command = 8; /* 10 bit, channel 0 */
        while (ad_result_lo & 0x08); /* wait until A/D is done */
        temp |= (((unsigned int)(ad_result_hi) << 8)
            + ad_result_lo >> 6) & 0x03FF;
        break;

    case 63:
        temp |= ((BILEVEL1 & 0x0002) > 0) * 1023;
        break;
}

SHIFT_REG = temp; /* output word to the shift register */

MMP = temp;

if (list_ptr >= list_len[active_list])
{ /* Reached end of list. Start new list */
    list_ptr = 0;
    active_list ^= 1; /* Change lists */
    list_change = 1; /* signal new list */
}

/* now get the mux ready for the next read */

```



```

MMP_LD_LO = (0x400 << active_list) + list_ptr;
temp = MMP & 0xFC00; /* clear lower 10 bits */

switch (temp >> 10)
{
    case 0:
        MUXSET = 0x0000;
        break;

    case 1:
        MUXSET = 0x003F;
        break;

    case 4:
        MUXSET = 0x0001;
        break;

    case 6:
        MUXSET = 0x004F;
        break;

    case 10:
        MUXSET = 0x0002;
        break;

    case 11:
        MUXSET = 0x0003;
        break;

    case 14:
        MUXSET = 0x0004;
        break;

    case 15:
        MUXSET = 0x005F;
        break;

    case 17:
        MUXSET = 0x006F;
        break;

    case 19:
        MUXSET = 0x0005;
        break;

    case 21:
        MUXSET = 0x0006;
        break;

    case 22:
        MUXSET = 0x0007;
        break;

    case 23:
        MUXSET = 0x0008;
        break;

    case 25:
        MUXSET = 0x007F;
        break;

    case 27:
        MUXSET = 0x0009;
        break;

    case 28:
        MUXSET = 0x009F;
        break;
}

```

```

        case 33:
            MUXSET = 0x000A;
            break;

        case 35:
            MUXSET = 0x000B;
            break;

        case 39:
            MUXSET = 0x000C;
            break;

        case 43:
            MUXSET = 0x000D;
            break;

        case 44:
            MUXSET = 0x000E;
            break;

        case 47:
            MUXSET = 0x000F;
            break;

        case 48:
            MUXSET = 0x00AF;
            break;

        case 52:
            MUXSET = 0x001F;
            break;

        case 54:
            MUXSET = 0x002F;
            break;

        case 57:
            MUXSET = 0x00BF;
            break;

        case 59:
            MUXSET = 0x00CF;
            break;

        case 61:
            MUXSET = 0x00DF;
            break;

        case 62:
            MUXSET = 0x00EF;
            break;
    }

    break;
}

MMP_LD_LO = mem_ptr; /* before leaving, set MMP to what it was */
asm ANDB int_pending, #0x7F; /* clear external interrupt pending */
CLR_IRQ5; /* clear RCO falling */
}

/*****
/*
/* Name          Init_Internal_A2D -- Initialize internal A/D registers.
/*
/*
/*
/*
/* Synopsis      (void) Init_A2D_Board(
*/

```

```

/*                                     char mode - 8 bit (1) or 10 bit (0) */
/*                                     ) */
/*                                     */
/* Description   This function sets up the internal A/D. It first sets the */
/*               number of states used by the A/D in conversion and tracking.*/
/*               Then it sets the register IOC2 required to utilize the time */
/*               determined above. */
/*               */
/* Returns      void */
/*               */
/*               */
/*****
void Init_Internal_A2D(char mode)
{
    if (mode) ad_time = 0xA6; /* good speed for 8 bit (9.8uS) */
    else ad_time = 0xC7; /* good speed for 10 bit (13.3uS) */

    ioc2 = 1; /* use time in ad_time */
}

/*****
/*                                     */
/* Name           Init_CPU -- Routine to initialize the CPU board. Various */
/*               registers are set in preparation of operation. */
/*               */
/*               */
/* Synopsis       (void) Init_CPU(void) */
/*               */
/*               */
/* Description     This function sets up the SDACS to a predetermined state. */
/*               It clears interrupts 4 and 5. Then disables interrupts 0-6.*/
/*               Interrupt 7 is enabled (memory full). Next it inhibits the */
/*               the PCM clock & counter, and resets the PCM counter. */
/*               */
/*               */
/* Returns        void */
/*               */
/*               */
/*****
void Init_CPU()
{
    CLR_IRQ4; /* clear the flip-flop holding RCO rising */
    CLR_IRQ5; /* clear the flip-flop holding RCO falling */
    EXT_IRQ_INHIBIT; /* inhibit all 8 external interrupts */
    PCM_CLK_STOP; /* stop the PCM clock */
    PCM_COUNT_STOP; /* disable PCM output counter */
    MMP_COUNT_UP; /* Have MMP count up one each time accessed */
    MMP_COUNT_ENABLE; /* Enable MMP to count each time accessed */
    MMP_LD_LO = 0; /* set main mem ptr to point to location 0 */
    MMP_LD_HI = 0; /* set main mem ptr to point to location 0 */
    MMP_BANKA; /* Set main memory to memory bank A (00) */
    CLK_ENABLE; /* Enable the clock oscillator. Turn on CLK */
    CLK_UPDATE; /* Start updating the clock registers */
    CLK_SQW_ON; /* Enable the square wave output of the CLK */
    EXT_BRD = (struct external_board *)BASE_BRD; /* point to first */
    /* external board */
    Init_Interrupt(0,0,0,0,0); /* Clear pending registers and mask */
    ioc1 = 0x20; /* Set EXTINT to only be triggered by PORT */
    /* 2.2 and TXD to be PORT 2.1 */
}

/*****
/*                                     */
/* Name           list_extract - Transfers data from current list to meas. */
/*               */
/*               */
/*               */
/* Synopsis       (void) list_extract(void) */
/*               */
/*               */

```

```

/* Description  This function reads the latest data from the list and */
/*             inserts the data into the measurement structure. Since the */
/*             data is operated on only while in the measurement structure, */
/*             this is required. */
/* Returns      void. */
/*             */
/*             */
/*****
void list_extract(void)
{
    j = active_list ^ 1; /* assign old list to j */

    for (i=0; i<list_len[j]; i++)
    {
        mem_ptr = (0x0400 << j) + i; /* point to list array */
        MMP_LD_LO = mem_ptr;
        k = MMP; /* store the list variable pointed to */

        mem_ptr = ((k & 0xFC00) >> 10) * 8 + value; /* here in meas */
        MMP_LD_LO = mem_ptr;
        MMP = k & 0x03FF;
    }
}

/*****
/* Name          sloper -- Routine calculates the slope of the line from */
/*              off-min to off-max. */
/*              */
/*              */
/* Synopsis      (void) sloper(void) */
/*              */
/* Description    This function computes the slope of the lines used to */
/*              determine the off nominal value. It nominalizes the slope */
/*              to 30000 in order to maximize the precision of integer math. */
/*              If the resulting slope is less than 2, a value of 2 is used. */
/*              */
/* Returns      void. */
/*              */
/*              */
/*****
void sloper(void)
{
    i = 0;

    while(i < num_meas_in_group)
    {
        MMP_LD_LO = i * 8 + off_max;
        j = MMP;

        MMP_LD_LO = i * 8 + off_min;
        k = MMP;

        if (j > k) l = 30000/(j - k);
        else l = 30000/(k - j);

        if (l < 2) l = 2;
        MMP_LD_LO = i * 8 + slope;
        MMP = l;

        MMP_LD_LO = i * 8 + blk_size;
        i += MMP;
    }
}

/*****

```

```

/*
/* Name      off_nom -- Routine calculates the off-nominal value of the
/*            variable.
/*
/*
/*
/* Synopsis  (int) off_nom(
/*            int meas_num - index of the measurement in
/*            question.
/*            )
/*
/*
/* Description This function computes the fuzzy value associated with being
/* off nominal. It uses the global variables describing the
/* off-nominal function associated with each measurement. For
/* speed concerns, the only function allowed is a simple line
/* from the minimum value to the maximum value of what is
/* considered off-nominal. Also, the function is assumed to
/* be symmetric about the nominal point, and thus the absolute
/* value of the difference between nominal and the current
/* value is used.
/*
/*
/* Although it is customary to use values from 0 to 1 as the
/* output of the fuzzy computation, this routine returns an
/* integer value from 10 to 100. This allows for the use of the
/* faster integer arithmetic.
/*
/*
/* Returns    The integer value returned is the fuzzy measurement of how
/* far off nominal the measurement is. The value ranges from
/* 10 (within normal parameters) and 100 (considered completely
/* abnormal).
/*
/*
/*
/*
/*****
void off_nom(void)
{
    j = off_nom_num = nom_num = 0;
    while(j < num_meas_in_group)
    {
        mem_ptr = j * 8 + value;
        MMP_LD_LO = mem_ptr;
        k = MMP;

        mem_ptr = j * 8 + nominal;
        MMP_LD_LO = mem_ptr;
        l = MMP;

        if (k > l) i = k - l;
        else i = l - k;

        mem_ptr = j * 8 + off_min;
        MMP_LD_LO = mem_ptr;
        if (i <= MMP)
        {
            mem_ptr = j * 8 + fuzz;
            MMP_LD_LO = mem_ptr;
            MMP = 10;
            nom_list[nom_num++] = j;
        }
        else
        {
            mem_ptr = j * 8 + off_max;
            MMP_LD_LO = mem_ptr;
            if (i >= MMP)
            {
                mem_ptr = j * 8 + fuzz;
                MMP_LD_LO = mem_ptr;
                MMP = 10 + max_priority_range;
            }
        }
    }
}

```

```

        off_nom_list[off_nom_num++] = j;
    }
    else
    {
        mem_ptr = j * 8 + off_min;
        MMP_LD_LO = mem_ptr;
        i -= MMP;
        mem_ptr = j * 8 + slope;
        MMP_LD_LO = mem_ptr;
        i *= MMP;
        i /= max_priority_divisor;
        mem_ptr = j * 8 + fuzz;
        MMP_LD_LO = mem_ptr;
        MMP = i + 10;
        off_nom_list[off_nom_num++] = j;
    }
}
mem_ptr = j * 8 + blk_size;
MMP_LD_LO = mem_ptr;
j += MMP;
}
}

/*****
/*
/* Name      rel_freq -- Routine calculates the relative frequency of
/*           each measurement, as well as the length of the
/*           measurement list.
/*
/* Synopsis  (void) rel_freq(void)
/*
/* Description This function computes the relative frequency by summing the
/*           fuzzy off-normal measurement values, and then dividing each
/*           off-normal measurement into the sum. This value is used to
/*           determine how often the measurement will occur in the list
/*           of measurements. For example, a value of 7 would indicate
/*           this measurement occurs every 7 samples.
/*
/*           This function also computes the length of the measurement
/*           list by dividing the sum of the measurement priorities by 2.
/*
/* Returns    void.
/*
*****/
void rel_freq(void)
{
    i = j = 0;

    while(i < num_meas_in_group)
    {
        mem_ptr = i * 8 + fuzz;
        MMP_LD_LO = mem_ptr;
        l = MMP;
        mem_ptr = i * 8 + blk_size;
        MMP_LD_LO = mem_ptr;
        if (l > 10)
        {
            j += (l * MMP);
        }
        else
        {
            j += 10;
        }
        i += MMP;
    }

    i = 0;
    while(i < num_meas_in_group)

```

```

    {
        mem_ptr = i * 8 + fuzz;
        MMP_LD_LO = mem_ptr;
        l = MMP;
        mem_ptr = i * 8 + rf;
        MMP_LD_LO = mem_ptr;
        MMP = (j*10) / l;
        mem_ptr = i * 8 + blk_size;
        MMP_LD_LO = mem_ptr;
        i += MMP;
    }

    if (j/2 > max_list_len)
        list_len[active_list ^ 1] = max_list_len;
    else
        list_len[active_list ^ 1] = j / 2;
}

/*****
/*
/* Name          stuff_list -- This routine inserts the information into the
/*              data list.
/*
/* Synopsis      (void) stuff_list(void)
/*
/* Description    Using the relative frequency (RF) of the data, "stuff_list"
/*              inserts the data into the list, beginning with the lowest
/*              relative frequency (highest priority data). The RF is used
/*              to determine how often the measurement is inserted. Once
/*              the lowest RF data is inserted, the next lowest is inserted.
/*              If the desired slot is occupied, the next available is taken.
/*
/* Returns       void.
/*
*****/
void stuff_list(void)
{
    m = active_list ^ 1; /* use the idle list */

    disable();
    MMP_LD_LO = (0xG400 << m);
    MMP_COUNT_ENABLE;
    for (i = 0; i < max_list_len; i++) MMP = 0; /* clear list */
    MMP_COUNT_DISABLE;
    enable();

    /* Sort the off-nominal list so smallest RF is first. */
    for (i = 0; i < off_nom_num; i++)
    {
        for (j = 1; j < off_nom_num; j++)
        {
            mem_ptr = off_nom_list[j] * 8 + rf;
            MMP_LD_LO = mem_ptr;
            l = MMP;
            mem_ptr = off_nom_list[i] * 8 + rf;
            MMP_LD_LO = mem_ptr;
            if (l < MMP)
            {
                l = off_nom_list[i];
                off_nom_list[i] = off_nom_list[j];
                off_nom_list[j] = l;
            }
        }
    }

    /* First, stuff in the off nominal measurements and their blocks */

```

```

for (i = 0; i < off_nom_num; i++)
{
    mem_ptr = off_nom_list[i] * 8 + rf;
    MMP_LD_LO = mem_ptr;
    n = MMP;
    for (j = 0; j < 10 * list_len[m]; j += n)
    {
        l = j / 10;
        mem_ptr = off_nom_list[i] * 8 + blk_size;
        MMP_LD_LO = mem_ptr;
        o = MMP;
        for (k = 0; k < o; k++)
        {
            mem_ptr = (0x0400 << m) + l;
            MMP_LD_LO = mem_ptr;
            if (!(MMP & 0x00FF))
            { /* slot is open. Insert this item into list here. */
                MMP = 1 + ((off_nom_list[i] + k) << 10);
                l++;
            }
            else
            { /* slot is NOT open. Look for next available space. */
                if(++l >= list_len[m])
                { /* At the end of the list. No more in this block can fit. */
                    break;
                }
                else
                { /* Let's see if this block is open. */
                    k--;
                    continue;
                }
            }
        }
    }
}

/* Now fill list with the nominal measurements. */
l = 0;
while (l < list_len[m])
{
    i = 0;
    do /* use do..while to ensure at least one pass in case nom_num=0 */
    {
        mem_ptr = (0x0400 << m) + l;
        MMP_LD_LO = mem_ptr;
        if (!(MMP & 0x00FF))
        { /* slot is open. Insert this item into list here. */
            MMP = 1 + (nom_list[i] << 10);
            i++;
            l++;
        }
        else
        { /* slot is NOT open. Look for next available space. */
            if(++l >= list_len[m])
            { /* At the end of the list. No more in this block can fit. */
                break;
            }
            else
            { /* Let's see if this block is open. */
                continue;
            }
        }
    } while (i < nom_num);
}

/*****

```



```

/*
/* Name          Init_PCM -- Routine to initialize the PCM port.
/*
/*
/* Synopsis      (void) Init_PCM(void)
/*
/*
/* Description    This function sets up the PCM port. It enables the clocks
/*                to the counter and the shift register, resets the counter,
/*                enables the RCO signal, and enables the shift register
/*                specific clock. This routine does NOT enable the interrupts
/*                available from the PCM system.
/*
/* Returns       void
/*
/*
/*****
void Init_PCM(void)
{
    PCM_CLK_GO;
    PCM_COUNT_GO;
    PCM_RCO_GO;
    PCM_SR_GO;

    /* For this Fuzzy demo, the hardware requires the following to enable clk */
    CLK_ENABLE;
    CLK_SQW_ON;
    IRQ5_ENABLE; /* Enable RCO falling */
}

/*****
/*
/* Name          Init_Interrupt -- This sets the interrupt masks.
/*
/*
/* Synopsis      (void) Init_Interrupt(
/*                char chg - if 0, change all four
/*                regs to exactly the four values.
/*                If 1, toggle the regs bits that
/*                correspond to the bits set in the
/*                variables. If 2, set the reg bits
/*                corresponding to the bits set in
/*                the variables. If 3, clear the
/*                reg bits corresponding to the
/*                bits set in the variables.
/*                char pend1 - intr pending register #1
/*                char pend2 - intr pending register #2
/*                char mask1 - intr mask register #1
/*                char mask2 - intr mask register #2
/*
/*
/* Description    This function is used to modify the interrupt controlling
/*                registers. The pending registers signal an interrupt is
/*                pending whether or not the corresponding mask is set. The
/*                two mask registers determine if the pending registers
/*                trigger the CPU to cause an interrupt vector to occur.
/*
/*
/* Returns       void
/*
/*
/*****
void Init_Interrupt(char chg, char pend1, char pend2, char mask1, char mask2)
{
    switch(chg)
    {
        case 0: /* set the registers to values shown in the variables */
            int_pending = pend1;

```

```

        ipend1 = pend2;
        int_mask = mask1;
        imask1 = mask2;
        break;
case 1: /* toggle (XOR) bits in registers that are set in variables */
    asm
    {
        XORB int_pending,pend1;
        XORB ipend1,pend2;
        XORB int_mask,mask1;
        XORB imask1,mask2;
    }
    break;
case 2: /* set only specified bits */
    asm
    {
        ORB int_pending,pend1;
        ORB ipend1,pend2;
        ORB int_mask,mask1;
        ORB imask1,mask2;
    }
    break;
case 3: /* clear only specified bits */
    pend1 ^= 0xFF;
    pend2 ^= 0xFF;
    mask1 ^= 0xFF;
    mask2 ^= 0xFF;
    asm
    {
        ANDB int_pending,pend1;
        ANDB ipend1,pend2;
        ANDB int_mask,mask1;
        ANDB imask1,mask2;
    }
    break;
    }
}

/*****
/*
/* Name          main -- Primary routine of program.
/*
/*
/* Synopsis      (void) main(void)
/*
/* Description    This function tests the validity of the fuzzy TM idea.
/*
/*
/* Returns       Void.
/*
/*
*****/

void main(void)
{
    disable_pts();
    Init_CPU();
    Init_Internal_A2D(0);

    initialize_list();

    list_len[0] = list_len[1] = num_meas_in_group;

    frame_position = 0; /* start at position zero (SFID) */
    active_list = 0;
    list_ptr = 0;
    list_change = 0;
    MUXSET = 0; /* Initialize mux to channel 0 */

```

```

    for (i = 0; i < list_len[0]; i++)
    {
        MMP_LD_LO = i * 8 + value;
        j = (i << 10) + MMP;
        MMP_LD_LO = 0x0400 + i;
        MMP = j;
        MMP_LD_LO = 0x0800 + i;
        MMP = j;
    }

    /***** Prepare the initial list *****/
    sloper();
    list_extract();
    off_nom();
    rel_freq();
    stuff_list();

    enable();
    Init_Interrupt(2,0,0,0x80,0); /* enable only the external interrupt */
    Init_PCM();

    /***** Loop forever. The actual output is interrupt driven *****/

    while (1 == 1)
    {
        if (list_change)
        { /***** Calculate a new list when previous list is transmitted */

            list_extract();
            off_nom();
            rel_freq();
            stuff_list();

            list_change = 0;
        }
    }
}

```

Appendix C

The following software listing is of the program used to decommutate the data from the adaptive TM.

```

/*****
/*
/* TMDISPLA.C This program is a stand alone software package designed to
/* interface with a PC decommutation card. It controls the
/* decommutation card and displays the information read by the
/* card on the screen. The PCM format assumed is that used by
/* fuzzy TM LDRD project.
/*
/*
/* AUTHOR: Ronald E. Kidner, 2664
/*
/* LANGUAGE: Microsoft C 7.0
/*
/* MACHINE: IBM PC Compatable
/*
/* DATE OF LATEST REVISION: 13 May 1993
/*
/*
/*****/

#include <bios.h>
#include <dos.h>
#include <decl.h>
#include <conio.h>
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <graph.h>

/*****
/* Internal Functions */
/*****/
void updatescn(void);
interrupt far handler(void);
void debrief(void);
int readkbd(void);
void init(void);
void test_intr(void);
unsigned char test, testie;

/*****
/* Display attributes */
/*****/
#define NORMAL 0X50 /* black on white */
#define HIGHLIGHT 0X30 /* black on lt blue */
#define RED 0x4f /* white on red */
#define GREEN 0x2f /* white on green */
#define BLUE 0x1f /* white on blue */
#define YELLOW 0x0e /* yellow on black */

/*****
/* Box, Line attributes */
/*****/
#define HORIZ 1
#define VERT 0
#define SINGLE 0
#define DOUBLE 15
#define TRUE 1
#define FALSE 0

/*****
/* decom board addresses */
/*****/
#define pgm_mode 0x81
#define pgm_8255 (char *)0xd000c003
#define pgm_1 0xfa /* lower 8 bits of counter load */
#define pgm_2 0x47 /* upper 3 bits of counter load */
#define pgm_3 0x40

```

```

#define reset_ptr (char *)0xd000c002
#define sync_mode 0x80
#define sync_8255 (char *)0xd000c803
#define sync_1 0xfa
#define sync_2 0xf3
#define sync_3 0x20
#define mux_low (char *)0xd000da00
#define clr_nmi (char *)0xd000d800
#define nmi 0x0a
#define time_iv 0x1c
#define channel_check 0x21
#define decomp_start (char *)0xd000d7fa

unsigned char data_hi, data_lo; /* hold the latest data transmitted */

void far *old_com;

char interrupt_mask, ireq;
char far *decomp_buffer; /* decomp addresses */
char far *decomp_reset;
char far *clr_nmi_ptr;
char far *mux_low_ptr;
char time_prev, old_index;

int old_value;

long test_pass, test_prev, test_fail;

char *gpin;

struct DISPLAY_PARMS { /* array of main channel display parameters*/
    short x,y;
    short low_thresh,hi_thresh;
    short low_flag,hi_flag; };

struct DISPLAY_PARMS mc_display[] = {
( 3, 4, 490, 510, BLUE, RED ), /* MAIN 1 */
( 3, 5, 0, 1023, BLUE, RED ), /* SUB 1A */
( 3, 6, 0, 1023, BLUE, RED ), /* SUB 1B */
( 3, 7, 0, 1023, BLUE, RED ), /* SUB 1C */
( 11, 4, 96, 100, BLUE, RED ), /* MAIN 2 */
( 11, 5, 0, 1023, BLUE, RED ), /* SUB 2A */
( 11, 6, 0, 1023, BLUE, RED ), /* SUB 2B */
( 11, 7, 0, 1023, BLUE, RED ), /* SUB 2C */
( 11, 8, 0, 1023, BLUE, RED ), /* SUB 2D */
( 11, 9, 0, 1023, BLUE, RED ), /* SUB 2E */
( 19, 4, 90, 110, BLUE, RED ), /* MAIN 3 */
( 27, 4, 96, 160, BLUE, RED ), /* MAIN 4 */
( 27, 5, 0, 1023, BLUE, RED ), /* SUB 4A */
( 27, 6, 0, 1023, BLUE, RED ), /* SUB 4B */
( 35, 4, 108, 112, BLUE, RED ), /* MAIN 5 */
( 35, 5, 0, 1023, BLUE, RED ), /* SUB 5A */
( 35, 6, 0, 1023, BLUE, RED ), /* SUB 5B */
( 35, 7, 0, 1023, BLUE, RED ), /* SUB 5C */
( 35, 8, 0, 1023, BLUE, RED ), /* SUB 5D */
( 43, 4, 800, 1000, BLUE, RED ), /* MAIN 6 */
( 43, 5, 0, 1023, BLUE, RED ), /* SUB 6A */
( 51, 4, 30, 120, BLUE, RED ), /* MAIN 7 */
( 59, 4, 5, 15, BLUE, RED ), /* MAIN 8 */
( 67, 4, 1, 1023, BLUE, RED ), /* MAIN 9 */
( 67, 5, 0, 1023, BLUE, RED ), /* SUB 9A */
( 67, 6, 0, 1023, BLUE, RED ), /* SUB 9B */
( 67, 7, 0, 1023, BLUE, RED ), /* SUB 9C */
( 75, 4, 150, 210, BLUE, RED ), /* MAIN 10 */
( 75, 5, 0, 1023, BLUE, RED ), /* SUB 10A */
( 75, 6, 0, 1023, BLUE, RED ), /* SUB 10B */
( 75, 7, 0, 1023, BLUE, RED ), /* SUB 10C */

```

```

( 75, 8, 0, 1023, BLUE, RED ), /* SUB 10D */
( 75, 9, 0, 1023, BLUE, RED ), /* SUB 10E */
( 3, 15, 565, 745, BLUE, RED ), /* MAIN 11 */
( 3, 16, 0, 1023, BLUE, RED ), /* SUB 11A */
( 11, 15, 80, 160, BLUE, RED ), /* MAIN 12 */
( 11, 16, 0, 1023, BLUE, RED ), /* SUB 12A */
( 11, 17, 0, 1023, BLUE, RED ), /* SUB 12B */
( 11, 18, 0, 1023, BLUE, RED ), /* SUB 12C */
( 19, 15, 95, 105, BLUE, RED ), /* MAIN 13 */
( 19, 16, 0, 1023, BLUE, RED ), /* SUB 13A */
( 19, 17, 0, 1023, BLUE, RED ), /* SUB 13B */
( 19, 18, 0, 1023, BLUE, RED ), /* SUB 13C */
( 27, 15, 60, 100, BLUE, RED ), /* MAIN 14 */
( 35, 15, 650, 910, BLUE, RED ), /* MAIN 15 */
( 35, 16, 0, 1023, BLUE, RED ), /* SUB 15A */
( 35, 17, 0, 1023, BLUE, RED ), /* SUB 15B */
( 43, 15, 10, 50, BLUE, RED ), /* MAIN 16 */
( 43, 16, 0, 1023, BLUE, RED ), /* SUB 16A */
( 43, 17, 0, 1023, BLUE, RED ), /* SUB 16B */
( 43, 18, 0, 1023, BLUE, RED ), /* SUB 16C */
( 43, 19, 0, 1023, BLUE, RED ), /* SUB 16D */
( 51, 15, 0, 90, BLUE, RED ), /* MAIN 17 */
( 51, 16, 0, 1023, BLUE, RED ), /* SUB 17A */
( 59, 15, 200, 260, BLUE, RED ), /* MAIN 18 */
( 59, 16, 0, 1023, BLUE, RED ), /* SUB 18A */
( 59, 17, 0, 1023, BLUE, RED ), /* SUB 18B */
( 59, 18, 0, 1023, BLUE, RED ), /* SUB 18C */
( 59, 19, 0, 1023, BLUE, RED ), /* SUB 18D */
( 59, 20, 0, 1023, BLUE, RED ), /* SUB 18E */
( 67, 15, 0, 120, BLUE, RED ), /* MAIN 19 */
( 67, 16, 0, 1023, BLUE, RED ), /* SUB 19A */
( 67, 17, 0, 1023, BLUE, RED ), /* SUB 19B */
( 75, 15, 1022, 1024, BLUE, RED ); /* MAIN 20 */

/*****/

void main(void)
{
    init(),

    old_index = test = testie = 0;
    old_value = -123;

    while( readkbd() )
    {
        updatescnf();
    }
    debrief();
}

/*****/

void updatescn(void)
{
    char s[15], index;
    int attribute;
    int value, i;

    index = data_hi >> 2; /* strip off lower 2 bits */
    value = (data_hi << 6) & 0x00FF; /* keep lower 2 bits */
    value <<= 2; /* shift the 2 bits into 9 & 10 positions */
    value |= data_lo; /* include lower 8 bits. Now it's a 10 bit word*/

    if (old_value == -123)
    {
        old_index = index;
        old_value = value;
    }
}

```

```

    }

    if (old_index != index)
    {
        if (old_value > mc_display[old_index].hi_thresh )
        {
            attribute = mc_display[old_index].hi_flag;
        }
        else
        {
            if (old_value < mc_display[old_index].low_thresh )
            {
                attribute = mc_display[old_index].low_flag;
            }
            else
            {
                attribute = GREEN;
            }
        }
    }
    xyprintf(mc_display[old_index].x,mc_display[old_index].y,
            attribute,"%4u",old_value);

    xyprintf(mc_display[index].x,mc_display[index].y,
            YELLOW,"%4u",value);

    old_index = index;
    old_value = value;
}
_strdate(s);
speedscn(s,7,24,9,1,NORMAL);
_strtime(s);
speedscn(s,7,25,9,1,NORMAL);

/* if (test_prev == test_pass)
{
    if (time_prev != s[10])
    {
        *decom_reset |= 0x80;
        *decom_reset &= 0x7F;
        time_prev = s[10];
    }
}
else
{
    test_prev = test_pass;
    time_prev = s[10];
}
*/
xyprintf( 34,24, NORMAL,"%6ld", test_pass );
xyprintf( 52,24, BLUE,   "%3d", test_fail );

if( (*decom_reset & 8) == 0) speedscn(" LOCK ",73,24,8,1,NORMAL);
else
    speedscn(" SEARCH ",73,24,8,1,RED);
}

/*****

interrupt far handler(void)      /* decom interrupt handler */
{
    char i;                      /* misc var */

    if( ( (decom_buffer[0] & 0xff) == sync_1 ) &&
        ( (decom_buffer[1] & 0xff) == sync_2 ) &&
        ( (decom_buffer[2] & 0xff) == sync_3 ) )
    {
        test_pass++;
        if( test_pass > 999999L ) test_pass = 1;
    }
}

```



```

        data_hi = decom_buffer[4]; /* high byte */
        data_lo = decom_buffer[5]; /* low byte */
    }
    else
    {
        *decom_reset |= 0x80;
        *decom_reset &= 0x7f;
        test_fail++;
    }

    i=*clr_nmi_ptr;
    outp(0x20,0x20);
}

/*****

int readkbd(void)          /* read keyboard */
{
    int ch,i;
    if( ( ch = csts() ) )
        switch( ch ) {
            case 59 : return FALSE;      /* F1 Quit program */

            case 60 :                    /* F2 Reset system board */
                init();
                break;
        }
    return TRUE;
}

/*****

void debrief(void)        /* end program stuff */
{
    *decom_reset |= 0x80;                /* reset decom board */
    coffscn(FALSE);                     /* turn on cursor */
    vertscn(1,1,80,25,25,NORMAL,TRUE);   /* clear screen */
    _clearscreen(_GCLEARSCREEN);
}

/*****

void init(void)
{
    void far *pointer;
    char far *decompointer;
    char s[10];
    int i,j,int_mask;

    test_fail = test_prev = 0;

    coffscn(TRUE);                      /* turn cursor off */
    vertscn(1,1,80,25,25,NORMAL,TRUE);   /* clear screen */

    boxscn(1,1,80,22,DOUBLE,NORMAL);     /* draw main box */

    linescn(8,1,21,SINGLE,2,2,NORMAL,VERT);
    linescn(16,1,21,SINGLE,2,2,NORMAL,VERT);
    linescn(24,1,21,SINGLE,2,2,NORMAL,VERT);
    linescn(32,1,21,SINGLE,2,2,NORMAL,VERT);
    linescn(40,1,21,SINGLE,2,2,NORMAL,VERT);
    linescn(48,1,21,SINGLE,2,2,NORMAL,VERT);
    linescn(56,1,21,SINGLE,2,2,NORMAL,VERT);
    linescn(64,1,21,SINGLE,2,2,NORMAL,VERT);
    linescn(72,1,21,SINGLE,2,2,NORMAL,VERT);
    linescn(1,11,8,SINGLE,2,1,NORMAL,HORIZ);
    linescn(8,11,9,SINGLE,1,1,NORMAL,HORIZ);

```

```

linescn(16,11,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(24,11,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(32,11,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(40,11,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(48,11,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(56,11,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(64,11,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(72,11,9,SINGLE,1,2,NORMAL,HORIZ);
linescn(1,12,8,SINGLE,2,1,NORMAL,HORIZ);
linescn(8,12,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(16,12,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(24,12,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(32,12,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(40,12,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(48,12,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(56,12,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(64,12,9,SINGLE,1,1,NORMAL,HORIZ);
linescn(72,12,9,SINGLE,1,2,NORMAL,HORIZ);

speedscn("GRP 1",2,2,5,1,HIGHLIGHT);
speedscn("GRP 2",10,2,5,1,HIGHLIGHT);
speedscn("GRP 3",18,2,5,1,HIGHLIGHT);
speedscn("GRP 4",26,2,5,1,HIGHLIGHT);
speedscn("GRP 5",34,2,5,1,HIGHLIGHT);
speedscn("GRP 6",42,2,5,1,HIGHLIGHT);
speedscn("GRP 7",50,2,5,1,HIGHLIGHT);
speedscn("GRP 8",58,2,5,1,HIGHLIGHT);
speedscn("GRP 9",66,2,5,1,HIGHLIGHT);
speedscn("GRP 10",74,2,6,1,HIGHLIGHT);
speedscn("GRP 11",2,13,6,1,HIGHLIGHT);
speedscn("GRP 12",10,13,6,1,HIGHLIGHT);
speedscn("GRP 13",18,13,6,1,HIGHLIGHT);
speedscn("GRP 14",26,13,6,1,HIGHLIGHT);
speedscn("GRP 15",34,13,6,1,HIGHLIGHT);
speedscn("GRP 16",42,13,6,1,HIGHLIGHT);
speedscn("GRP 17",50,13,6,1,HIGHLIGHT);
speedscn("GRP 18",58,13,6,1,HIGHLIGHT);
speedscn("GRP 19",66,13,6,1,HIGHLIGHT);
speedscn("GRP 20",74,13,6,1,HIGHLIGHT);

speedscn("Adaptive Telemetry PCM Decomutation",2,23,35,1,NORMAL);
speedscn("Decom Status:",59,24,13,1,NORMAL);
speedscn("F1-EXIT",18,25,7,1,NORMAL);
speedscn("F2-RESET",27,25,8,1,NORMAL);
speedscn("Frames: Valid = ",18,24,16,1,NORMAL);
speedscn("Invalid = ",42,24,10,1,NORMAL);
speedscn("                                ",16,23,37,1,NORMAL);
speedscn("                                ",54,23,27,1,NORMAL);

_strdate(s);
speedscn("Date:",2,24,5,1,NORMAL);
speedscn(s,7,24,9,1,NORMAL);

_strtime(s);
speedscn("Time:",2,25,5,1,NORMAL);
speedscn(s,7,25,9,1,NORMAL);
time_prev = s[10];

pointer = handler;                /* set decom IV          */
_dos_setvect(nmi,pointer);

decom_buffer = decom_start;       /* set buffer pointer    */
decom_reset = reset_ptr;         /* set reset pointer     */
decompointer = pgm_8255;         /* set decom board      */
clr_nmi_ptr = clr_nmi;          /* set clr nmi ptr      */
mux_low_ptr = mux_low;

```

```

*decompointer = pgm_mode ;          /* program 8255      */
*(decompointer-1) = pgm_3;
*(decompointer-2) = pgm_2;
*(decompointer-3) = pgm_1;

decompointer = sync_8255;          /* sync word 8255    */
*decompointer = sync_mode;

*(decompointer-1) = sync_3;
*(decompointer-2) = sync_2;
*(decompointer-3) = sync_1;

i=*mux_low_ptr;                    /* reset mux_low ff   */
*decom_reset |= 0x80;
*decom_reset &= 0x7f;
i=*clr_nmi_ptr;

/* *decompointer = 0x0E ;          /* send reset off     */
}

/*****

```

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