Implementing the Color Space Transformation Algorithm Using the TMS320C2xx

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Implementing the Color Space Transformation Algorithm Using the TMS320C2xx

Abstract

The Texas Instruments (TI™) TMS320 family of digital signal processors (DSPs) is widely used for digital image processing. Color space transformation, one of the basic image processing algorithms, is used for digital still camera, color printer, color scanner, and other video product applications.

This application report describes how to implement the algorithm of transforming the image color space from (R, G, B) to (Y, U, V) using TMS320C2xx assembly language. With the information provided, users can implement other color space transformations, such as (Y, U, V) to (R, G, B), (R, G, B) to (Y, Cr, Cb), etc., by modifying the transformation coefficient matrix.

.

Introduction

Many different color spaces are used to represent a color image, for example, (R, G, B), (Y, U, V), (Y, Cr, Cb), (Y, I, Q), etc. Equation 1 represents the general formula for the color space transformation.

$$\begin{bmatrix} S_1' \\ S_2' \\ S_3' \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{23} & C_{33} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix} \quad \text{(Equation 1)}$$

where

$[S_1\ S_2\ S_3]^T$ is the original color space.

$[S_1'\ S_2'\ S_3']^T$ is the transformed color space.

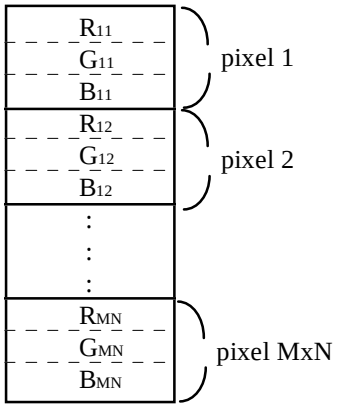
$\left[C_{i,j}\right]$ is the coefficient matrix of transformation.

Equation 2 transforms (R, G, B) space to (Y, U, V) space.

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.148 & -0.289 & 0.437 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad \text{(Equation 2)}$$

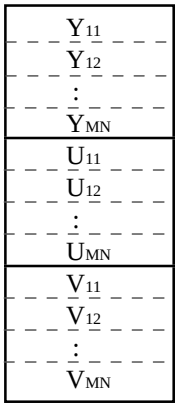
Assume that the size of an image frame is M x N pixels, where M is the number of pixels/line, N is the number of lines/frame, and each pixel contains three pieces of information: R, G, and B. The data is stored in memory as shown in Figure 1.

Figure 1. Image Data (R, G, B) Storage Format in Memory



After calculating Equation 2, the transformed data (Y, U, V) is stored in another section of memory, as shown in Figure 2.

Figure 2. Image Data (Y, U, V) Storage Format in Memory



Software Description

Variable Declaration and Initial Values

The transformation program includes the following variables:

INPUT DATA: {R_{11}, G_{11}, B_{11}, R_{12}, G_{12}, B_{12}, ..., R_{MN}, G_{MN}, B_{MN}}

OUTPUT DATA {Y_{11}, Y_{12}, ..., Y_{MN}}
{U_{11}, U_{12}, ..., U_{MN}}
{V_{11}, V_{12}, ..., V_{MN}}

COEFFICIENTS: {C_{11}, C_{12}, C_{13}
C_{21}, C_{22}, C_{23}
C_{31}, C_{32}, C_{33}}

Example 1 shows how to define the variables in 'C2xx assembly language code.

Example 1. Defining Variables in 'C2xx Assembly Language Code

```
;-----------------------------------------------------------------------
;     Define variables & data blocks
;-----------------------------------------------------------------------
C11         .usect  ".r2y_var", 1                   ; coefficients of transformation matrix
C12         .usect  ".r2y_var", 1
C13         .usect  ".r2y_var", 1
C21         .usect  ".r2y_var", 1
C22         .usect  ".r2y_var", 1
C23         .usect  ".r2y_var", 1
C31         .usect  ".r2y_var", 1
C32         .usect  ".r2y_var", 1
C33         .usect  ".r2y_var", 1

RGB_BLOCK   .usect  ".rgb_blk", 3*8*8               ; input data array
Y_BLOCK     .usect  ".yuv_blk", 8*8                 ; output data arrays
U_BLOCK     .usect  ".yuv_blk", 8*8
V_BLOCK     .usect  ".yuv_blk", 8*8
```

Define the initial values of the coefficients in the .data section as shown in Example 2.

Example 2. Initial Values of Coefficients Defined in .data Section

```
                .data
;-----------------------------------------------------------------------
;     Y         0.299   0.587   0.114                   R
;     U   =    -0.148  -0.289   0.437     G
;     V         0.615   -0.515  -0.100     B
;-----------------------------------------------------------------------
R2Y_COFF    .word   32768*299/1000,  32768*587/1000,  32768*114/1000
            .word  -32768*148/1000, -32768*289/1000,  32768*437/1000
            .word   32768*615/1000, -32768*515/1000, -32768*100/1000
```

Initialize these coefficients in the program, as shown in Example 3.

Example 3. Initializing Coefficients in the Program

```
;---------------------------------------------------------
;     RGB to YUV coefficient initialization
;---------------------------------------------------------
RGB2YUV_INIT:
      SPM    0
      SETC   SXM
      CLRC   OVM
      MAR    *, AR2
      LAR    AR2, #C11
      RPT    #9-1
      BLPD   #R2Y_COFF, *+
      RET
```

Transforming (R, G, B) to (Y, U, V)

We use four auxiliary registers as pointers to the input data section (RGB_BLOCK) and output data sections (Y_BLOCK, U_BLOCK, V_BLOCK) (see Example 4).

Example 4. Pointing to the Input and Output Data Sections

```
RGB2YUV:
;---------------------------------------------------------
;     AR assignment:
;     AR2 -> RGB_BLOCK
;     AR3 -> Y_BLOCK
;     AR4 -> U_BLOCK
;     AR5 -> V_BLOCK
;     AR6 -> Counter for frame
;     AR7 -> Counter for line
;---------------------------------------------------------
      LAR    AR0, #2
      LAR    AR2, #RGB_BLOCK
      LAR    AR3, #Y_BLOCK
      LAR    AR4, #U_BLOCK
      LAR    AR5, #V_BLOCK
      LAR    AR6, #64-1
      MAR    *, AR2
      LDP    #C11
```

Then calculate (Y, U, V) from the input data (R, G, B),

Example 5. Calculating (Y, U, V) From the Input Data (R, G, B)

```
;-----------------------------------------------------------------
;     RGB to YUV Transformation:
;
;     Y          C11   C12   C13        R
;     U     =    C21   C22   C23        G
;     V          C31   C32   C33        B
;-----------------------------------------------------------------
R2Y_LOOP:
     LT    *+                                        ; Y1 = C11 * R + C12 * G + C13 * B
     MPY   C11
     LTP   *+
     MPY   C12
     LTA   *0-, AR3                        ; AR3 -> Y_BLOCK
     MPY   C13
     APAC
     SACH  *+, 1, AR2

     LT    *+                                        ; U = C21 * R + C22 * G + C23 * B
     MPY   C21
     LTP   *+
     MPY   C22
     LTA   *0-, AR4                        ; AR4 -> U_BLOCK
     MPY   C23
     APAC
     SACH  *+, 1, AR2

     LT    *+                                         ; V = C31 * R + C32 * G + C33 * B
     MPY   C31
     LTP   *+
     MPY   C32
     LTA   *+, AR5                          ; AR5 -> V_BLOCK
     MPY   C33
     APAC
     SACH  *+, 1, AR6

     BANZ  R2Y_LOOP, *-, AR2

     RET
```

Note that Cijs are in S.Q15 format, and input data are in S16.Q0 format. After multiplying input data with Ci,j, the result stored in the Product register is in S17.Q15 format. Because PM=0, which is set in RGB2YUV_INIT, the data in the accumulator will be in S17.Q15 format. Therefore, the data in the accumulator needs to be shifted one bit left before storing back to the memory. The instruction to store with shifr is

SACH *+, **1**, ARx

The complete assembly file, linker command file, and testing pattern file are attached in the appendixes that follow.

Appendix A. RGB2YUV.ASM

```
;-------------------------------------------------------------------------------------------------
;       Filename:               RGB2YUV.ASM
;       Description:            Color space transformation {R,G,B} to {Y,U,V}
;       Author:                 Vivian Shao
;       Date:                   03/20/1997
;-------------------------------------------------------------------------------------------------
            .def   start
            .def   RGB2YUV_INIT, RGB2YUV

            .data
;-------------------------------------------------------------------------------------------------
;       Y           0.299    0.587    0.114              R
;       U     =     -0.148   -0.289   0.437              G
;       V           0.615    -0.515   -0.100             B
;-------------------------------------------------------------------------------------------------
R2Y_COFF
          .word    32768*299/1000,  32768*587/1000,  32768*114/1000
          .word   -32768*148/1000, -32768*289/1000,  32768*437/1000
          .word    32768*615/1000, -32768*515/1000, -32768*100/1000

;-------------------------------------------------------------------------------------------------
;       Define variables & data blocks
;-------------------------------------------------------------------------------------------------
C11       .usect  ".r2y_var", 1
C12       .usect  ".r2y_var", 1
C13       .usect  ".r2y_var", 1
C21       .usect  ".r2y_var", 1
C22       .usect  ".r2y_var", 1
C23       .usect  ".r2y_var", 1
C31       .usect  ".r2y_var", 1
C32       .usect  ".r2y_var", 1
C33       .usect  ".r2y_var", 1

RGB_BLOCK    .usect  ".rgb_blk", 3*8*8
Y_BLOCK      .usect  ".yuv_blk", 8*8
U_BLOCK      .usect  ".yuv_blk", 8*8
V_BLOCK      .usect  ".yuv_blk", 8*8

;-------------------------------------------------------------------------------------------------
;       RGB2YUV CODE SECTION
;-------------------------------------------------------------------------------------------------
          .text
start:
            CALL    RGB2YUV_INIT
            CALL    RGB2YUV
            B       start

;-------------------------------------------------------------------------------------------------
;       RGB to YUV coefficient initialization
;-------------------------------------------------------------------------------------------------
RGB2YUV_INIT:
       SPM    0
       SETC   SXM
```

```
        CLRC  OVM
        MAR   *, AR2
        LAR   AR2, #C11
        RPT   #9-1
        BLPD  #R2Y_COFF, *+
        RET
;-------------------------------------------------------------------------------------------
;       RGB to YUV Transformation:
;
;       Y           C11   C12   C13     R
;       U     =     C21   C22   C23     G
;       V           C31   C32   C33     B
;-------------------------------------------------------------------------------------------
RGB2YUV:
;-------------------------------------------------------------------------------------------
;       AR assignment:
;       AR2 -> RGB_BLOCK
;       AR3 -> Y_BLOCK
;       AR4 -> U_BLOCK
;       AR5 -> V_BLOCK
;       AR6 -> Counter for frame
;       AR7 -> Counter for line
;-------------------------------------------------------------------------------------------
        LAR     AR0, #2
        LAR     AR2, #RGB_BLOCK
        LAR     AR3, #Y_BLOCK
        LAR     AR4, #U_BLOCK
        LAR     AR5, #V_BLOCK
        LAR     AR6, #64-1
        MAR     *, AR2
        LDP     #C11
;-------------------------------------------------------------------------------------------
;       Multiplication:
;           Cij:            S.Q15
;           R,G,B:          S16.Q0
;           ACC:            S17.Q15 (PM=0)
;       Need the integer part (S16) => SACH x,1 ; shift left 1 bit
;-------------------------------------------------------------------------------------------
R2Y_LOOP:
        LT      *+                      ; Y1 = C11 * R + C12 * G + C13 * B
        MPY     C11
        LTP     *+
        MPY     C12
        LTA     *0-, AR3                ; AR3 -> Y_BLOCK
        MPY     C13
        APAC
        SACH    *+, 1, AR2

        LT      *+                      ; U = C21 * R + C22 * G + C23 * B
        MPY     C21
        LTP     *+
        MPY     C22
        LTA     *0-, AR4                ; AR4 -> U_BLOCK
        MPY     C23
        APAC
```

```
SACH    *+, 1, AR2

LT      *+                      ; V = C31 * R + C32 * G + C33 * B
MPY     C31
LTP     *+
MPY     C32
LTA     *+, AR5                 ; AR5 -> V_BLOCK
MPY     C33
APAC
SACH    *+, 1, AR6
BANZ    R2Y_LOOP, *-, AR2

RET
```

Appendix B. VECTORS.ASM

```
;-------------------------------------------------------------------------------------------
;       Filename: VECTORS.ASM
;       Description: Define vector table of C2xx
;
;       Author:   Vivian Shao
;       Date:     11/15/1996
;-------------------------------------------------------------------------------------------
          .def      reset
          .ref      start

          .sect     "vectors"
reset:    B         start
```

Appendix C. RGB2YUV.CMD

```
/*****************************************************************************/
/*                                                                           */
/*   Usage:      dsplnk <obj files...> -o <out file> -m <map file> lab.cmd    */
/*                                                                           */
/*****************************************************************************/
vectors.obj
rgb2yuv.obj
-v0
-m rgb2yuv.map
-o rgb2yuv.out

MEMORY
{
            /* Program Space */
   PAGE 0 :
        VECS            : origin =    0h , length =   040h        /* Vectors */
        PROG            : origin =  040h , length =  0FC0h        /* 4K ROM */

            /* Data Space */
   PAGE 1 :
        MMREGS          : origin =    0h , length =    60h        /* MMRS    */
        B2              : origin =  060h , length =   020h        /* On-chip DARAM B2 */
        B0              : origin = 0200h , length =  0100h        /* B0  */
        B1              : origin = 0300h , length =  0100h        /* B1 */
        VARS            : origin = 1000h , length =  0080h
        SARAM           : origin = 1080h , length =  0F80h        /* Internal RAM */
}

/*---------------------------------------------------------------------------*/
/* SECTIONS ALLOCATION                                                       */
/*---------------------------------------------------------------------------*/
SECTIONS
{
   vectors :    { } > VECS      PAGE 0          /*INTERRUPT VECTOR TABLE    */
   .text   :    { } > PROG      PAGE 0          /* CODE                     */
   .data   :    { } > PROG      PAGE 0          /*INITIALIZATION DATA TABLES */
   .bss    :    { } > B0        PAGE 1          /* UNINITIALIZED DATA       */
   .r2y_var:    { } > VARS      PAGE 1          /* variables in one page    */
   .rgb_blk:    { } > SARAM     PAGE 1          /* RGB data buffer          */
   .yuv_blk:    { } > SARAM     PAGE 1          /* YUV data buffer          */
}
```

Appendix D. RGB2YUV.LOG

```
wa st0>>13, ARP=,x
wa st0<<7, DP=,x
mem Y_BLOCK
fill 0x1080, 1, 1, 10
fill 0x1081, 1, 1, 20
fill 0x1082, 1, 1, 30
fill 0x1083, 1, 1, 10
fill 0x1084, 1, 1, 20
fill 0x1085, 1, 1, 30
fill 0x1086, 1, 1, 10
fill 0x1087, 1, 1, 20
fill 0x1088, 1, 1, 30
fill 0x1089, 1, 1, 10
fill 0x108a, 1, 1, 20
fill 0x108b, 1, 1, 30
fill 0x108c, 1, 1, 10
fill 0x108d, 1, 1, 20
fill 0x108e, 1, 1, 30
fill 0x108f, 1, 1, 10
fill 0x1090, 1, 1, 20
fill 0x1091, 1, 1, 30
fill 0x1092, 1, 1, 10
fill 0x1093, 1, 1, 20
fill 0x1094, 1, 1, 30
fill 0x1095, 1, 1, 10
fill 0x1096, 1, 1, 20
fill 0x1097, 1, 1, 30

fill 0x1098, 1, 1, 10
fill 0x1099, 1, 1, 20
fill 0x109a, 1, 1, 30
fill 0x109b, 1, 1, 10
fill 0x109c, 1, 1, 20
fill 0x109d, 1, 1, 30
fill 0x109e, 1, 1, 10
fill 0x109f, 1, 1, 20
fill 0x10a0, 1, 1, 30
fill 0x10a1, 1, 1, 10
fill 0x10a2, 1, 1, 20
fill 0x10a3, 1, 1, 30
fill 0x10a4, 1, 1, 10
fill 0x10a5, 1, 1, 20
fill 0x10a6, 1, 1, 30
fill 0x10a7, 1, 1, 10
fill 0x10a8, 1, 1, 20
fill 0x10a9, 1, 1, 30
fill 0x10aa, 1, 1, 10
fill 0x10ab, 1, 1, 20
fill 0x10ac, 1, 1, 30
fill 0x10ad, 1, 1, 10
fill 0x10ae, 1, 1, 20
fill 0x10af, 1, 1, 30
```

```
fill 0x10b0, 1, 1, 10
fill 0x10b1, 1, 1, 20
fill 0x10b2, 1, 1, 30
fill 0x10b3, 1, 1, 10
fill 0x10b4, 1, 1, 20
fill 0x10b5, 1, 1, 30
fill 0x10b6, 1, 1, 10
fill 0x10b7, 1, 1, 20
fill 0x10b8, 1, 1, 30
fill 0x10b9, 1, 1, 10
fill 0x10ba, 1, 1, 20
fill 0x10bb, 1, 1, 30
fill 0x10bc, 1, 1, 10
fill 0x10bd, 1, 1, 20
fill 0x10be, 1, 1, 30
fill 0x10bf, 1, 1, 10
fill 0x10c0, 1, 1, 20
fill 0x10c1, 1, 1, 30
fill 0x10c2, 1, 1, 10
fill 0x10c3, 1, 1, 20
fill 0x10c4, 1, 1, 30
fill 0x10c5, 1, 1, 10
fill 0x10c6, 1, 1, 20
fill 0x10c7, 1, 1, 30

fill 0x10c8, 1, 1, 10
fill 0x10c9, 1, 1, 20
fill 0x10ca, 1, 1, 30
fill 0x10cb, 1, 1, 10
fill 0x10cc, 1, 1, 20
fill 0x10cd, 1, 1, 30
fill 0x10ce, 1, 1, 10
fill 0x10cf, 1, 1, 20
fill 0x10d0, 1, 1, 30
fill 0x10d1, 1, 1, 10
fill 0x10d2, 1, 1, 20
fill 0x10d3, 1, 1, 30
fill 0x10d4, 1, 1, 10
fill 0x10d5, 1, 1, 20
fill 0x10d6, 1, 1, 30
fill 0x10d7, 1, 1, 10
fill 0x10d8, 1, 1, 20
fill 0x10d9, 1, 1, 30
fill 0x10da, 1, 1, 10
fill 0x10db, 1, 1, 20
fill 0x10dc, 1, 1, 30
fill 0x10dd, 1, 1, 10
fill 0x10de, 1, 1, 20
fill 0x10df, 1, 1, 30

fill 0x10e0, 1, 1, 10
fill 0x10e1, 1, 1, 20
fill 0x10e2, 1, 1, 30
fill 0x10e3, 1, 1, 10
fill 0x10e4, 1, 1, 20
```

```
fill 0x10e5, 1, 1, 30
fill 0x10e6, 1, 1, 10
fill 0x10e7, 1, 1, 20
fill 0x10e8, 1, 1, 30
fill 0x10e9, 1, 1, 10
fill 0x10ea, 1, 1, 20
fill 0x10eb, 1, 1, 30
fill 0x10ec, 1, 1, 10
fill 0x10ed, 1, 1, 20
fill 0x10ee, 1, 1, 30
fill 0x10ef, 1, 1, 10
fill 0x10f0, 1, 1, 20
fill 0x10f1, 1, 1, 30
fill 0x10f2, 1, 1, 10
fill 0x10f3, 1, 1, 20
fill 0x10f4, 1, 1, 30
fill 0x10f5, 1, 1, 10
fill 0x10f6, 1, 1, 20
fill 0x10f7, 1, 1, 30

fill 0x10f8, 1, 1, 10
fill 0x10f9, 1, 1, 20
fill 0x10fa, 1, 1, 30
fill 0x10fb, 1, 1, 10
fill 0x10fc, 1, 1, 20
fill 0x10fd, 1, 1, 30
fill 0x10fe, 1, 1, 10
fill 0x10ff, 1, 1, 20
fill 0x1100, 1, 1, 30
fill 0x1101, 1, 1, 10
fill 0x1102, 1, 1, 20
fill 0x1103, 1, 1, 30
fill 0x1104, 1, 1, 10
fill 0x1105, 1, 1, 20
fill 0x1106, 1, 1, 30
fill 0x1107, 1, 1, 10
fill 0x1108, 1, 1, 20
fill 0x1109, 1, 1, 30
fill 0x110a, 1, 1, 10
fill 0x110b, 1, 1, 20
fill 0x110c, 1, 1, 30
fill 0x110d, 1, 1, 10
fill 0x110e, 1, 1, 20
fill 0x110f, 1, 1, 30

fill 0x1110, 1, 1, 10
fill 0x1111, 1, 1, 20
fill 0x1112, 1, 1, 30
fill 0x1113, 1, 1, 10
fill 0x1114, 1, 1, 20
fill 0x1115, 1, 1, 30
fill 0x1116, 1, 1, 10
fill 0x1117, 1, 1, 20
fill 0x1118, 1, 1, 30
fill 0x1119, 1, 1, 10
```

```
fill 0x111a, 1, 1, 20
fill 0x111b, 1, 1, 30
fill 0x111c, 1, 1, 10
fill 0x111d, 1, 1, 20
fill 0x111e, 1, 1, 30
fill 0x111f, 1, 1, 10
fill 0x1120, 1, 1, 20
fill 0x1121, 1, 1, 30
fill 0x1122, 1, 1, 10
fill 0x1123, 1, 1, 20
fill 0x1124, 1, 1, 30
fill 0x1125, 1, 1, 10
fill 0x1126, 1, 1, 20
fill 0x1127, 1, 1, 30

fill 0x1128, 1, 1, 10
fill 0x1129, 1, 1, 20
fill 0x112a, 1, 1, 30
fill 0x112b, 1, 1, 10
fill 0x112c, 1, 1, 20
fill 0x112d, 1, 1, 30
fill 0x112e, 1, 1, 10
fill 0x112f, 1, 1, 20
fill 0x1130, 1, 1, 30
fill 0x1131, 1, 1, 10
fill 0x1132, 1, 1, 20
fill 0x1133, 1, 1, 30
fill 0x1134, 1, 1, 10
fill 0x1135, 1, 1, 20
fill 0x1136, 1, 1, 30
fill 0x1137, 1, 1, 10
fill 0x1138, 1, 1, 20
fill 0x1139, 1, 1, 30
fill 0x113a, 1, 1, 10
fill 0x113b, 1, 1, 20
fill 0x113c, 1, 1, 30
fill 0x113d, 1, 1, 10
fill 0x113e, 1, 1, 20
fill 0x113f, 1, 1, 30
```