RZ/A2M Group

2D Barcode Application Note for GR-MANGO

Introduction

This document describes a sample program for decoding 2D barcodes using the RZ/A2M.

Target Device

RZ/A2M

Contents

1. Overview

This application note describes a sample program for decoding 2D barcodes using the dynamic reconfigurable processor (DRP). The open-source project ZXing (short for Zebra Crossing) is used as the algorithm for decoding 2D barcodes.

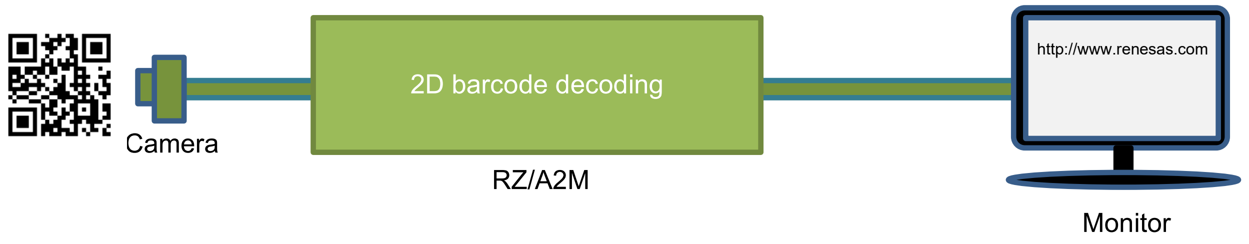


Figure 1.1 System Overview of Sample Program

Table 1.1 Camera Input Specifications

Input image format	Bayer format (8 bpp)
Image capture size	1280 × 720
Capture frame rate	30 fps

Table 1.2 Display Output Specifications

Output image format	Grayscale format (8 bpp)
Output image display size	1280 × 720
Image display frame rate	60 fps

1.1 Processing Overview

The sample program performs two types of processing: “Simple ISP,” which converts an image captured in Bayer format into an image suitable for 2D barcode decoding, and “ZXing,” which scans the 2D barcode from the image converted by "Simple ISP". For details of these two types of processing, refer to 5.1, Simple ISP, and 5.2, ZXing.

Figure 1.2 and Figure 1.3 show a system block diagram and flowchart of the sample program.

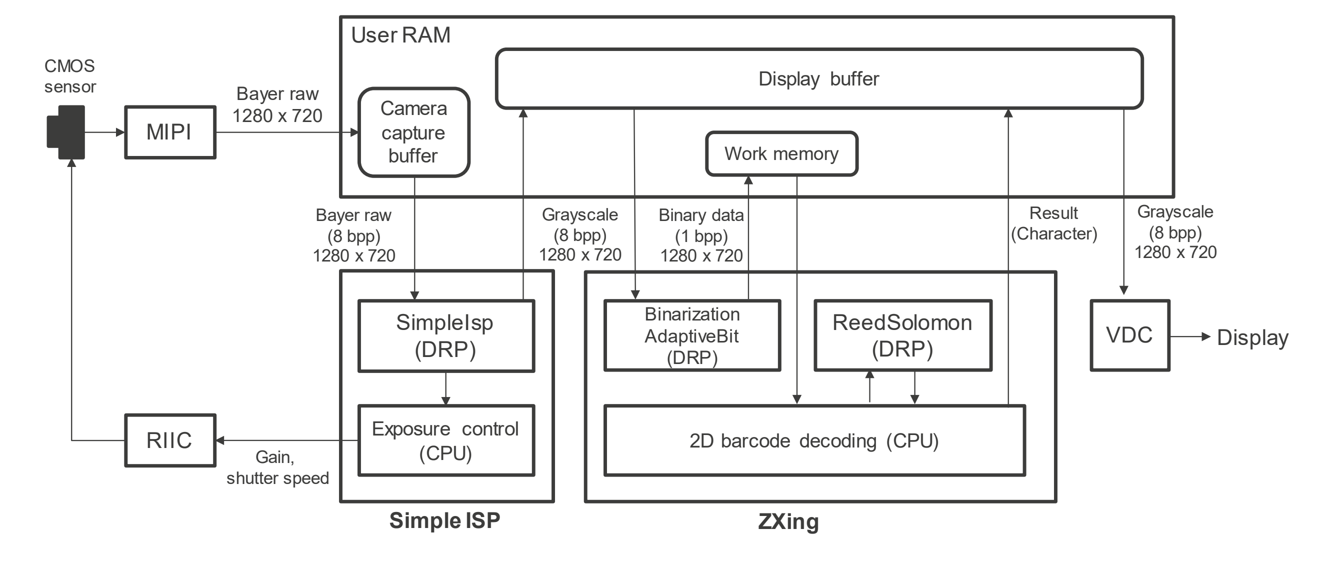


Figure 1.2 System Block Diagram of 2D Barcode Sample Program

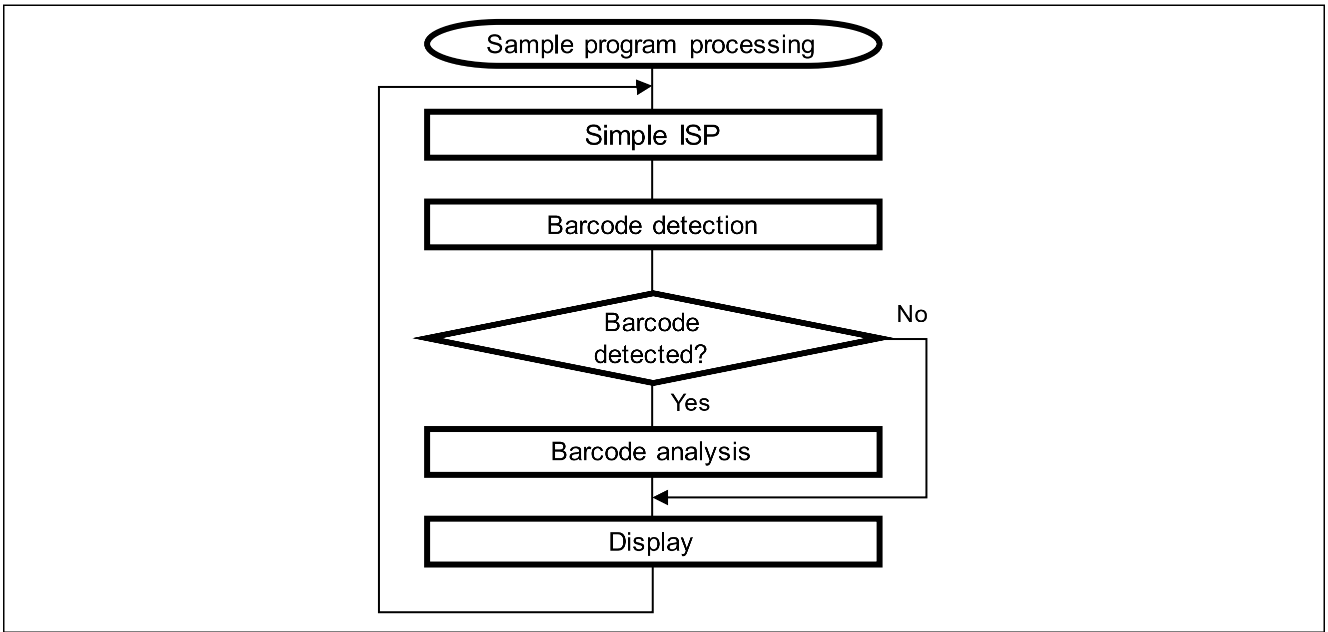


Figure 1.3 Flowchart of 2D Barcode Sample Program

1.1.1 Simple ISP

"Simple ISP" processing employs “exposure control,” “demosaicing,” “noise reduction,” “sharpening,” and “gamma correction.”

The results of “color component accumulation” are used for "exposure control".

In “demosaicing” the image is converted from Bayer format to grayscale format.

In “noise reduction” median filtering is used to remove noise from the format-converted image data in order to increase the accuracy (the barcode recognition rate) of ZXing.

In “sharpening” an unsharp masking algorithm is used to increase the sharpness of the image data following "noise reduction".

In “gamma correction” compensation is applied using a gamma value of 1.2.

1.1.2 ZXing

In this processing stage the barcode contained in the preprocessed image is read, and the decoded result is output.

The barcode types supported by ZXing and, of these, the type supported by the sample program, are listed below.

Table 1.3 Barcode Types

Barcode	Supported
1D barcodes	-
QR codes	✓
Aztec codes	-
DataMatrix	-
PDF417	-

In the sample program, portions of the binarization and decoding (Reed-Solomon decoding) processing of ZXing have been modified to enable them to run on the DRP. Details of the changes are presented in 5.2, ZXing.

1.2 DRP Library

The DRP library enables a variety of functions to be implemented on the DRP incorporated into the RZ/A2M. For details, refer to RZ/A2M Group DRP Library User's Manual (R01US0367).

The sample program uses the library functions listed below.

Table 1.4 Library Functions Used

Library Name	Tile Number	Description
Simple ISP	6	Color component accumulation, demosaicing, noise reduction, sharpening, and gamma correction
BinarizationAdaptiveBit	3	Binarization (adaptive threshold) (bit output)
ReedSolomon	1	Reed-Solomon decoding

1.3 Operation Confirmation Environment

Figure 1.4 shows the environment used to confirm operation of the sample program.

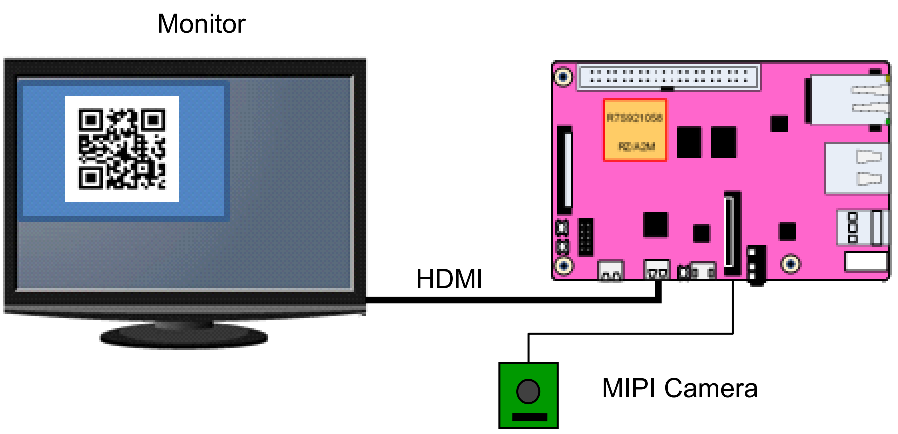


Figure 1.4 Operation Confirmation Environment

2. Operation Confirmation Conditions

The operation of the sample code has been confirmed under the conditions listed below.

Table 2.1 Operation Confirmation Conditions

Item	Description
MCU used	RZ/A2M
Operating frequency*[1]	CPU clock (Iϕ): 528 MHz Image processing clock (Gϕ): 264 MHz Internal bus clock (Bϕ): 132 MHz Peripheral clock 1 (P1ϕ): 66 MHz Peripheral clock 0 (P0ϕ): 33 MHz OM_SCLK: 132 MHz CKIO: 132 MHz
Operating voltage	Power supply voltage (I/O): 3.3 V Power supply voltage (1.8/3.3 V switchable I/O (PVcc_SPI)): 3.3 V Power supply voltage (Internal): 1.2 V
Integrated development environment	e2 studio (Refer to the release notes for e2 studio version.)
C compiler	GNU Arm Embedded 6.3.1.20170620
	Compiler options (excluding directory path) Release: -mcpu=cortex-a9 -march=armv7-a -marm -mlittle-endian -mfloat-abi=hard -mfpu=neon -mno-unaligned-access -Os -ffunction-sections -fdata-sections -Wunused -Wuninitialized -Wall -Wextra -Wmissing-declarations -Wconversion -Wpointer-arith -Wpadded -Wshadow -Wlogical-op -Waggregate-return -Wfloat-equal -Wnull-dereference -Wmaybe-uninitialized -Wstack-usage=100 -DNO_ICONV -fabi-version=0 Hardware Debug: -mcpu=cortex-a9 -march=armv7-a -marm -mlittle-endian -mfloat-abi=hard -mfpu=neon -mno-unaligned-access -Og -ffunction-sections -fdata-sections -Wunused -Wuninitialized -Wall -Wextra -Wmissing-declarations -Wconversion -Wpointer-arith -Wpadded -Wshadow -Wlogical-op -Waggregate-return -Wfloat-equal -Wnull-dereference -Wmaybe-uninitialized -g3 -Wstack-usage=100 -DNO_ICONV -fabi-version=0
Operating mode	Boot mode 6 (Octa Flash boot 1.8 V products)
Board used	GR-MANGO Rev.B
Camera used	Raspberry Pi Camera V2
Monitor used	Monitor with Full-WXGA (1,366 × 768) resolution
Device used (functionality used on the board)	Octa flash memory(connected to Octa bus space) Manufacturer: Macronix, model name: MX25UW12845GXDIO0 EP952(HDMI Transmitter)

Note: 1. This is the operating frequency used in clock mode 1 (24 MHz clock input on EXTAL pin).

3. Related Application Notes

Documents related to this application note are listed below. Refer to them in conjunction with this document.

RZ/A2M Group RZ/A2M Software Core Package (R01AN5680)
(The latest version can be downloaded from the Renesas Electronics website.)

RZ/A2M Group DRP Driver User's Manual (R01US0355)
(The latest version can be downloaded from the Renesas Electronics website.)

RZ/A2M Group DRP Library User's Manual (R01US0367)
(The latest version can be downloaded from the Renesas Electronics website.)

4. File Structure

For the file structure, refer to the release note for the RZ/A2M Group 2D Barcode Package for GR-MANGO(R01AN5850).

The following open-source software is bundled with the sample program.

Table 4.1 Bundled Open-Source Software

Name	Description
ZXing	This open-source software is distributed under the Apache 2.0 license. The Apache 2.0 license can be viewed here: http://www.apache.org/licenses/LICENSE-2.0. “ZXing” is a library for reading 1D and 2D barcodes. ZXing files are available for download here: https://github.com/zxing/zxing/. The sample program uses customized code based on the C++ version of ZXing (trunk@2890). Refer to the file structures for the location of the ZXing source code.
FreeRTOS	This open-source software is distributed under the MIT License. The MIT License can be viewed here: https://opensource.org/licenses/mit-license.php. FreeRTOS is a real-time operating system kernel for embedded devices. The sample program uses Kernel V10.0.0. Refer to the file structure for the location of the FreeRTOS source code.

5. Description of Sample Program

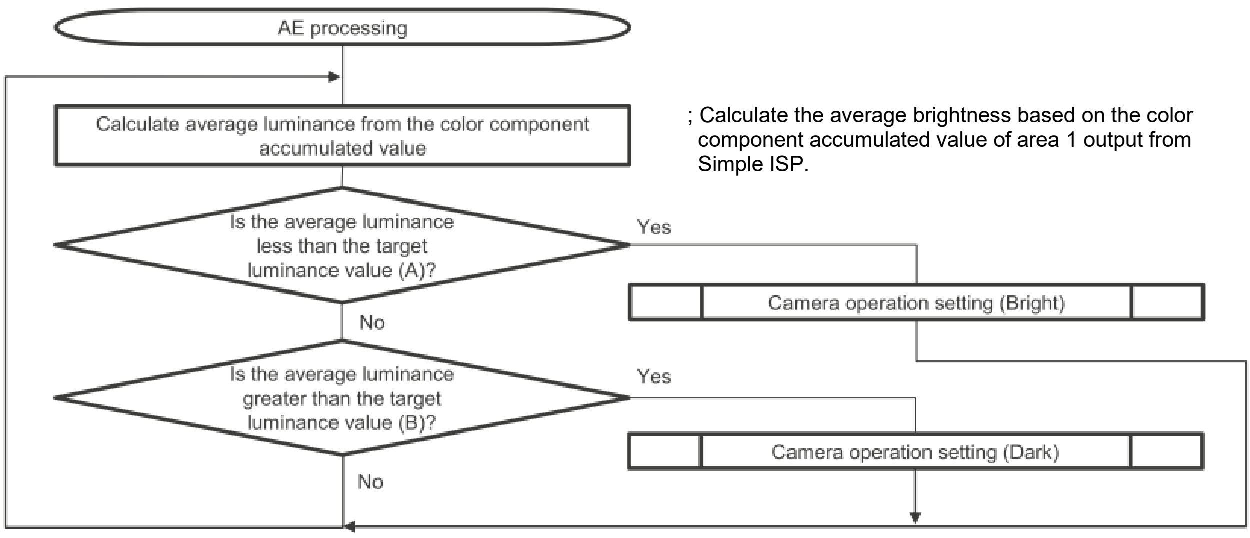
5.1 Simple ISP

This processing improves the quality of the image to boost barcode detection accuracy. It also converts the image to grayscale because ZXing does not utilize color information.

The Simple ISP function in the DRP library is used to perform the processing described below. For details of Simple ISP, refer to RZ/A2M Group DRP Library User's Manual (R01US0367).

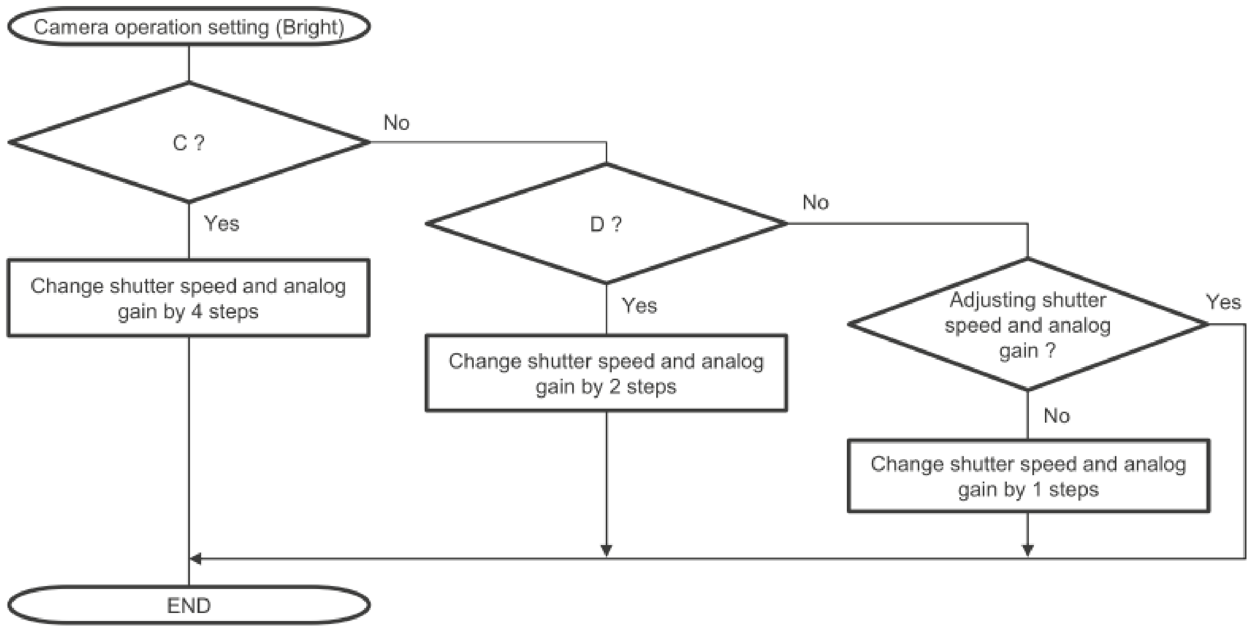
5.1.1 Automatic Exposure Correction (AE)

This processing corrects the camera's exposure (shutter speed and camera gain) based on the color component accumulated value of the output from Simple ISP. The camera's exposure corrects by the CPU. Figure 5.1, Figure 5.2, and Figure 5.3 are flowcharts of the camera control processing.



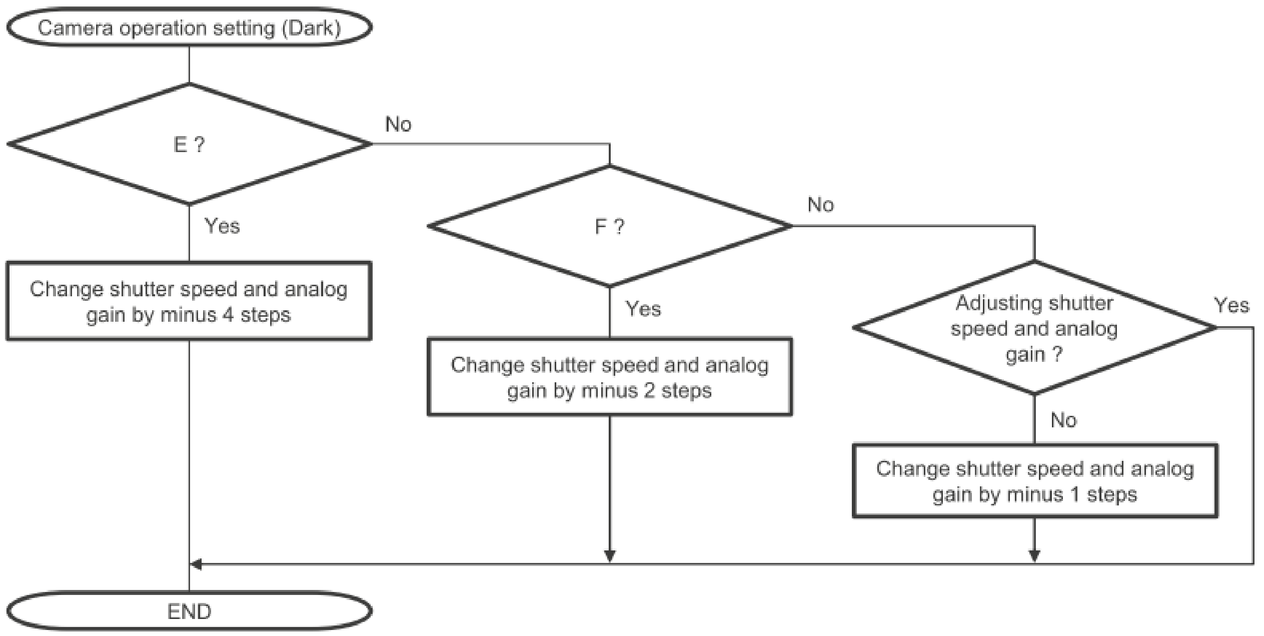
Note: A setting value suitable for 2D barcode decoding (104) ±10 is used as the target luminance (A = 94, B = 114).

Figure 5.1 AE Processing Flowchart



Note: C means the average luminance dropped significantly lower than the target luminance (< 64).
D means the average luminance dropped significantly lower than the target luminance (< 84).

Figure 5.2 Camera Operation Setting (Bright) Flowchart



Note: E means the average luminance rose significantly higher than the target luminance (> 144).
F means the average luminance rose significantly higher than the target luminance (> 124).

Figure 5.3 Camera Operation Setting (Dark) Flowchart

5.1.2 Demosaicing

Simple ISP is used to convert the input image from Bayer to grayscale format.

5.1.3 Noise Reduction

As part of Simple ISP processing, median filtering is applied to the data in grayscale format generated in 5.1.2, Demosaicing, in order to remove noise.

5.1.4 Sharpening

As part of Simple ISP processing, an unsharp masking algorithm is used to sharpen the image following removal of noise in 5.1.3, Noise Reduction.

5.1.5 Gamma Correction

As part of Simple ISP processing, gamma correction using LUT is performed on the image that was sharpened in 5.1.4, Sharpening.

5.2 ZXing

ZXing decodes a 1D or 2D barcode contained in an image and outputs the result.

ZXing consists of the following four processing stages:

- Binarization
- Marker detection (for QR codes)
- Normalization (for QR codes)
- Decoding (for QR codes)

Binarization is common to all types of barcode scanning. In the sample program, binarization is performed by the DRP.

The details of the other processing stages differ depending on the type of barcode. The sample program supports QR codes, and a portion of the decoding (Reed-Solomon decoding) is performed by the DRP.

The changes made to the original ZXing source code are described below.

5.2.1 Binarization

Refer to the table below for the changes made to the binarization source code to enable execution as a DRP library function.

Table 5.1 Location of Changes to Binarization Source Code

Item	Description
File incorporating changes	zxing/common/HybridBinarizer.cpp
Function incorporating changes	HybridBinarizer::getBlackMatrix()

```
/**
 * Calculates the final BitMatrix once for all requests. This could be called once from the
 * constructor instead, but there are some advantages to doing it lazily, such as making
 * profiling easier, and not doing heavy lifting when callers don't expect it.
 */
Ref<BitMatrix> HybridBinarizer::getBlackMatrix() {
  if (matrix_) {
    return matrix_;
  }
  LuminanceSource& source = *getLuminanceSource();
  int width = source.getWidth();
  int height = source.getHeight();
  if (width >= MINIMUM_DIMENSION && height >= MINIMUM_DIMENSION) {
    ArrayRef<char> luminances = source.getMatrix();

    PerformSetStartTime(9);

#ifndef ZXING_CPU_MODE
    Ref<BitMatrix> newMatrix (new BitMatrix(width, height));
    R_BCD_MainBinarization2((uint32_t)&luminances[0], (uint32_t)newMatrix->get_array_addr(), width, height)
    matrix_ = newMatrix;
#else //ZXING_CPU_MODE
    int subWidth = width >> BLOCK_SIZE_POWER;
    if ((width & BLOCK_SIZE_MASK) != 0) {
      subWidth++;
    }
    int subHeight = height >> BLOCK_SIZE_POWER;
    if ((height & BLOCK_SIZE_MASK) != 0) {
      subHeight++;
    }
    ArrayRef<int> blackPoints =
      calculateBlackPoints(luminances, subWidth, subHeight, width, height);

    Ref<BitMatrix> newMatrix (new BitMatrix(width, height));
    calculateThresholdForBlock(luminances,
                               subWidth,
                               subHeight,
                               width,
                               height,
                               blackPoints,
                               newMatrix);
    matrix_ = newMatrix;
#endif //ZXING_CPU_MODE

    PerformSetEndTime(9);

  } else {
    // If the image is too small, fall back to the global histogram approach.
    matrix_ = GlobalHistogramBinarizer::getBlackMatrix();
  }
  return matrix_;
}
```

Code after changes

Code before changes

Figure 5.4 Changes to Binarization Source Code

5.2.2 Reed-Solomon Decoding

Refer to the table below for the changes made to the Reed-Solomon decoding source code to enable execution as a DRP library function.

Table 5.2 Changes to Reed-Solomon Decoding Source Code

Item	Description
File incorporating changes	zxing/qrcode/decoder/Decoder.cpp
Function incorporating changes	Decoder::correctErrors()

Code after changes

Code before changes

```
void Decoder::correctErrors(ArrayRef<char> codewordBytes, int numDataCodewords) {
  int numCodewords = codewordBytes->size();
  int numECCodewords = numCodewords - numDataCodewords;

#ifndef ZXING_CPU_MODE
  bool ret = R_BCD_MainReedsolomon((int8_t *)&codewordBytes[0], numCodewords, numECCodewords);
  if (ret == false) {
    PerformSetEndTime(10);
    throw ChecksumException();
  }
#else // ZXING_CPU_MODE
  ArrayRef<int> codewordInts(numCodewords);
  for (int i = 0; i < numCodewords; i++) {
    codewordInts[i] = codewordBytes[i] & 0xff;
  }

  try {
    rsDecoder_.decode(codewordInts, numECCodewords);
  } catch (ReedSolomonException const& ignored) {
    (void)ignored;
    PerformSetEndTime(10);
    throw ChecksumException();
  }

  for (int i = 0; i < numDataCodewords; i++) {
    codewordBytes[i] = (char)codewordInts[i];
  }
#endif // ZXING_CPU_MODE
}
```

Figure 5.5 Changes to Reed-Solomon Decoding Source Code

5.3 Memory footprint

For the memory footprint, refer to the release note for the RZ/A2M Group 2D Barcode Package for GR-MANGO (R01AN5850).

6. Reference Documents

User's Manual: Hardware

RZ/A2M Group User's Manual: Hardware
(The latest version can be downloaded from the Renesas Electronics website.)

Arm Architecture Reference Manual ARMv7-A and ARMv7-R edition Issue C
(The latest version can be downloaded from the Arm website.)

Arm Cortex™-A9 Technical Reference Manual Revision: r4p1
(The latest version can be downloaded from the Arm website.)

Arm Generic Interrupt Controller Architecture Specification - Architecture version2.0
(The latest version can be downloaded from the Arm website.)

Arm CoreLink™ Level 2 Cache Controller L2C-310 Technical Reference Manual Revision: r3p3
(The latest version can be downloaded from the Arm website.)

Technical Update/Technical News

(The latest version can be downloaded from the Renesas Electronics website.)

User's Manual: Integrated Development

The user's manual of the e2 studio integrated development environment is available for download on the Renesas Electronics website.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Mar. 31, 2021	-	First edition issued

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   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.
2. Processing at power-on

   The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.
3. Input of signal during power-off state

   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.
4. Handling of unused pins

   Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.
5. Clock signals

   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.
6. Voltage application waveform at input pin

   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).
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