AN14172

在MCX N系列MCU上使用SmartDMA进行图形处理

第2.0版—2024年5月6日 应用笔记

文档信息

信息	内容
关键词	AN14172、MCX、MCU、SmartDMA、图形库、FRDM-MCXN947、FRDM-MCXN236
摘要	本应用笔记介绍了SmartDMA在图形处理上的应用。

1 介绍

本应用笔记介绍了SmartDMA在图形处理上的应用。除了通用的DMA功能外，它还支持数据格式处理。

所有的MCX N系列MCU均包含一个SmartDMA协处理器，可有效减轻Arm内核的负载并进行灵活的数据转换。

2 图形库支持的功能

图形库支持以下数据的处理：

- 通用DMA
- 大小端交换
- 倒序
- RGB565转RGB888
- ARGB转RGB
- ARGB转RGB，然后交换大小端
- ARGB转RGB，然后交换大小端并倒序

此处，ARGB中的A表示Alpha（透明度）。

3 相较于传统DMA的优势

DMA主要支持内存与外设之间、外设与外设之间、内存与内存之间的数据传输。除了访问所有的外设和内存之外，SmartDMA还可以执行指令代码、数学运算、数据翻转、移位、判断等操作。因此，SmartDMA比DMA更具灵活性。

在MCX N系列MCU上，FlexIO可用于驱动LCD屏幕。但有时数据会与预期不符，需要稍作调整。如果使用传统的DMA，则很难对数据进行预处理，此时就需要Arm内核来进行处理，但这会消耗更多的时间和负载。SmartDMA可用于预处理，然后将处理后的数据传输到FlexIO。

4 功能说明

SmartDMA可以实现多种功能。它可以作为通用DMA来传输数据，也可以实现数据格式处理，例如翻转字节、翻转位序、去除部分数据等。

4.1 通用DMA

SmartDMA可以访问所有的外设和存储区。它具有通用DMA的功能，如外设到外设、内存到内存、外设到内存、内存到外设的数据传输。

由于它可以执行编程指令，因此其功能可以更加灵活，参数也可以更加完整。

在本应用笔记中，演示使用的是最简单的通用DMA功能。SmartDMA将内存数据移至FlexIO外设的数据寄存器，FlexIO再将数据输出到LCD。

目前，通用DMA操作的功能比较简单。只需应用程序代码向SmartDMA提供要传输的数据地址和数据长度即可。

SmartDMA会自动将这些数据移入FlexIO数据寄存器。一旦FlexIO数据寄存器需要数据，它会自动向SmartDMA发出请求。

4.2 大小端交换

大小端交换表示字节顺序的交换。这里特指16位数据的中高低字节的交换。

例如：

输入数据：

字节格式的数据 [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 1A, 1B, 1C, 1D, 1E, 1F]

经过SmartDMA操作后，输出数据：

字节格式的数据 [1, 0, 3, 2, 5, 4, 7, 6, 9, 8, B, A, D, C, F, E, 11, 10, 13, 12, 15, 14, 17, 16, 19, 18, 1B, 1A, 1D, 1C, 1F, 1E]

在MCX N系列MCU中，FlexIO有8个数据寄存器。每个寄存器有4个字节。8个数据寄存器需要32字节的数据。因此，SmartDMA每次可以处理32字节的数据来发送到FlexIO。

4.3 倒序

此功能是指字节顺序的反转。换句话说，当向SmartDMA提供32字节的数据时，SmartDMA会将数据反转，并将结果数据放入8个FlexIO数据寄存器中。

例如：

输入数据：

字节格式的数据 [0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 1A, 1B, 1C, 1D, 1E, 1F]

经SmartDMA操作后，输出数据：

字节格式的数据 [1F, 1E, 1D, 1C, 1B, 1A, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, F, E, D, C, B, A, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0]

4.4 RGB565转RGB888

为了节省RAM空间，可以使用RGB565像素格式来存储图像数据。但有些液晶屏模块采用RGB888接口。SmartDMA可以实现RGB565到RGB888格式的转换。SmartDMA转换的结果可以直接发送到FlexIO的数据寄存器，而不增加对内存空间的占用。

4.5 ARGB转RGB

ARGB是带有一个alpha分量的RGB数据。有些原始图像数据是ARGB格式，但显示屏可能不支持这种格式。这种情况下，就需要从每个像素数据中去除alpha值，然后将其发送到显示接口。这种实现需要对每个像素进行处理，而SmartDMA可以轻松有效地去除alpha值。此外，SmartDMA还可以访问FlexIO的数据寄存器，并将转换后的数据直接发送到FlexIO的数据寄存器。

SmartDMA可以将ARGB转RGB、交换大小端、倒序等功能结合起来使用。其结果放置在FlexIO的数据寄存器中。

SmartDMA的灵活性和独立性可以从这些功能中得到验证。

5 软件说明

SmartDMA的任务执行指令被封装在一个数组中。开放了部分API函数供用户使用。本应用笔记中使用的函数已经加到了MCX N系列MCU的SDK中。

5.1 SDK示例的说明

在MCX N系列MCU的SDK中，有一个名为`lvgl_demo_widgets_bm`的示例。此示例用于演示LVGL窗口组件。

该示例使用FlexIO来模拟MCU8080接口，驱动一个3.5英寸的LCD屏幕。SmartDMA充当了通用DMA的功能，负责将数据传输到FlexIO的数据寄存器。

5.2 SmartDMA的函数数组

SmartDMA 的显示API可以在`fsl_smartdma_mcxn.h`文件中找到。代码片段如下所示：

```
/*!
* @brief The API index when using s_smartdmaDisplayFirmware.
*/
enum _smartdma_display_api
{
    kSMARTDMA_FlexIO_DMA_Endian_Swap = 0U,
    kSMARTDMA_FlexIO_DMA_Reverse32,
    kSMARTDMA_FlexIO_DMA,
    kSMARTDMA_FlexIO_DMA_Reverse,  /*!< Send data to FlexIO with reverse order.
 */
    kSMARTDMA_RGB565To888,  /*!< Convert RGB565 to RGB888 and save to output
 memory, use parameter
    smartdma_rgb565_rgb888_param_t. */
    kSMARTDMA_FlexIO_DMA_RGB565To888,  /*!< Convert RGB565 to RGB888 and send to
 FlexIO, use parameter
    smartdma_flexio_mculcd_param_t. */
    kSMARTDMA_FlexIO_DMA_ARGB2RGB,  /*!< Convert ARGB to RGB and send to FlexIO,
 use parameter
    smartdma_flexio_mculcd_param_t. */
    kSMARTDMA_FlexIO_DMA_ARGB2RGB_Endian_Swap, /*!< Convert ARGB to RGB, then
 swap endian, and send to FlexIO, use
    parameter smartdma_flexio_mculcd_param_t. */
    kSMARTDMA_FlexIO_DMA_ARGB2RGB_Endian_Swap_Reverse, /*!< Convert ARGB to RGB,
 then swap endian and reverse, and send
    to FlexIO, use parameter smartdma_flexio_mculcd_param_t. */
};
```

在`fsl_smartdma_mcxn.c`文件中，有个一名为`s_smartdmaDisplayFirmware`的数组，其中包含了SmartDMA函数的实现。将SmartDMA函数封装成一个数组中的目的是为了降低用户对SmartDMA的研究成本，并支持用户直接使用已实现的模块功能，从而能够更快地实现应用的功能。

5.3 SmartDMA的初始化

表1中所述的函数实现了SmartDMA的初始化。

表1. SmartDMA的初始化

例程	说明
SMARTDMA_InitWithoutFirmware	初始化SmartDMA
SMARTDMA_InstallFirmware	安装固件
SMARTDMA_InstallCallback	安装完整的回调函数
SMARTDMA_Boot	启动SmartDMA来运行程序
SMARTDMA_Deinit	取消初始化SmartDMA
SMARTDMA_Reset	重置SmartDMA
SMARTDMA_HandleIRQ	SMARTDMA中断请求
FLEXIO_MCULCD_SMARTDMA_Callback	SMARTDMA中断回调

5.3.1 初始化SmartDMA

要启用SmartDMA，请执行以下操作：

1. 清除SmartDMA的复位信号。
2. 将FlexIO IRQ设置为SmartDMA触发输入。
3. 启用SmartDMA的时钟。
4. 启用SmartDMA的IRQ。

5.3.2 安装SmartDMA固件

SmartDMA的功能模块必须放置在固定的内存地址上才能正常工作。在本应用程序中，必须将其置于0x04000000处，如下所示：

```
/*! @brief The firmware used for display. */
extern const uint8_t s_smartdmaDisplayFirmware[];
/*! @brief The s_smartdmaDisplayFirmware firmware memory address. */
#define SMARTDMA_DISPLAY_MEM_ADDR 0x04000000U
/*! @brief Size of s_smartdmaDisplayFirmware */
#define SMARTDMA_DISPLAY_FIRMWARE_SIZE (s_smartdmaDisplayFirmwareSize)
```

安装SmartDMA固件的过程本质上是将SmartDMA功能模块的代码数组复制到一个指定的RAM地址上，如下所示：

```
SMARTDMA_InstallFirmware(SMARTDMA_DISPLAY_MEM_ADDR, s_smartdmaDisplayFirmware,
 SMARTDMA_DISPLAY_FIRMWARE_SIZE);
```

5.3.3 SmartDMA的回调例程

SmartDMA可主动触发Arm内核的中断，如在数据传输结束后进行触发。

SmartDMA在Arm矢量表中有一个相应的中断号（`SMARTDMA_IRQHandler`）。在SmartDMA的配置阶段，可以安装一个回调函数，如下所示：

```
SMARTDMA_InstallCallback(FLEXIO_MCULCD_SMARTDMA_Callback, handle);
```

在回调函数中，Arm内核可以配置FlexIO，以允许任务继续进行。

5.3.4 启动SmartDMA的API

在应用程序中，定义一个结构体来设置与SmartDMA相关的参数。这些参数包括数据缓冲区的地址、数据传输的长度以及SmartDMA协议栈空间的地址。最重要的是找到一个必须从SmartDMA功能块代码执行的API。参见以下代码。

```
handle->smartdmaApi = (uint8_t)kSMARTDMA_FlexIO_DMA;
handle->smartdmaParam.p_buffer = (uint32_t *)(xfer->dataAddrOrSameValue +
 part1Len);
handle->smartdmaParam.buffersize = part2Len;
handle->smartdmaParam.smartdma_stack = handle->smartdmaStack;
SMARTDMA_Reset();
SMARTDMA_Boot(handle->smartdmaApi, &(handle->smartdmaParam), 0);
```

启动的过程是将相应API的地址赋给SmartDMA的程序计数器，然后就会开始执行函数块。

6 基于FRDM-MCXN947的演示介绍

下载MCX N MCU最新的SDK。打开示例`lvgl_demo_widgets_bm`的路径。根路径为：

`\boards\frdmmcxn947\lvgl_examples\lvgl_demo_widgets_bm\cm33_core0`

该工程主要演示了LVGL窗口组件的功能。通过使用FlexIO来模拟MCU8080接口实现了显示驱动程序。SmartDMA协助FlexIO将数据从RAM传输到数据寄存器。

图1所示为IAR工程。

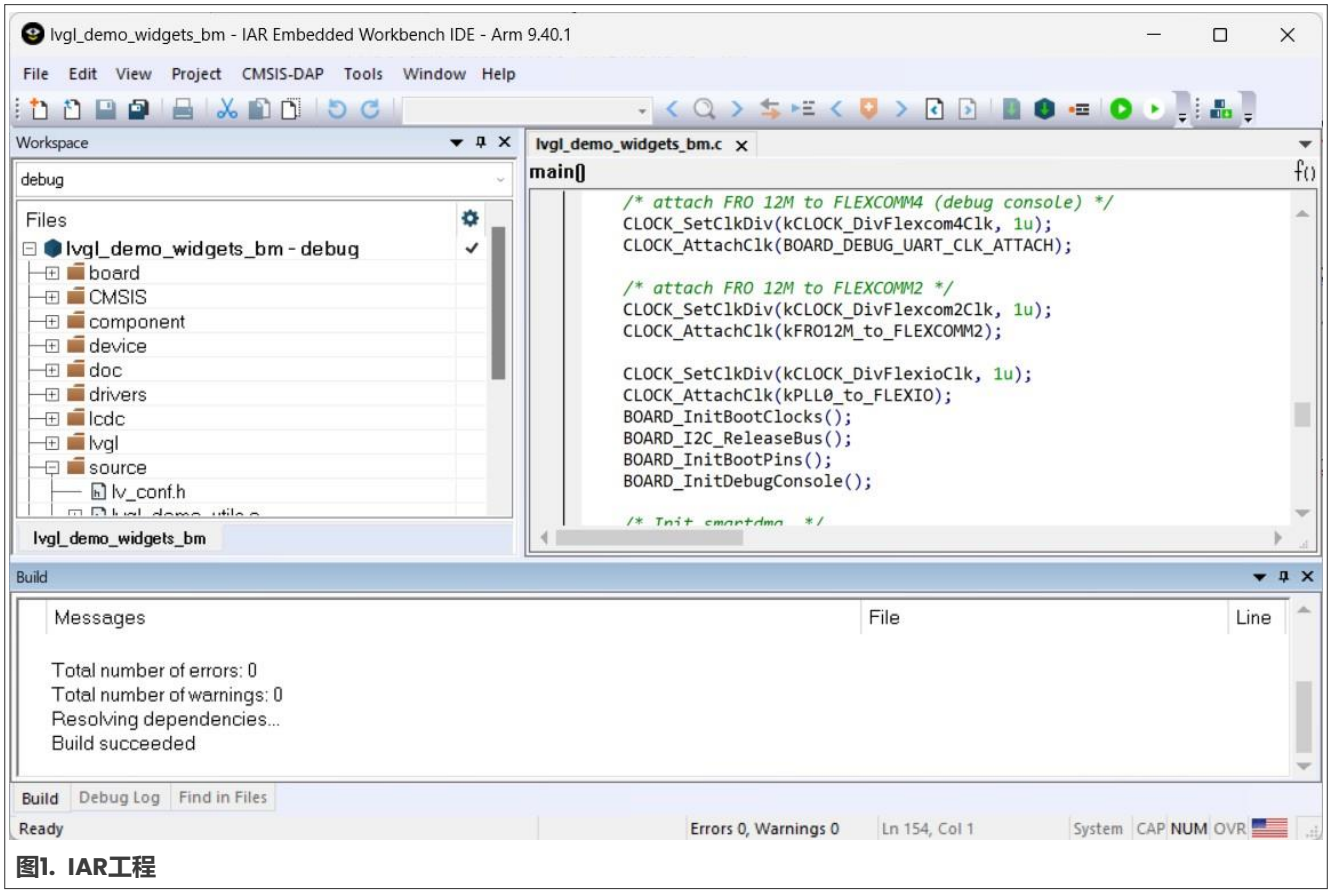

图1. IAR工程

为了展示SmartDMA的通用DMA功能，请执行以下步骤：

1. 将USB电缆连接至计算机和FRDM-MCXN947的端口J17。
2. 编译并下载代码。
3. 按下Reset按钮，代码开始运行。
4. 屏幕上将显示LVGL窗口组件演示的运行情况。

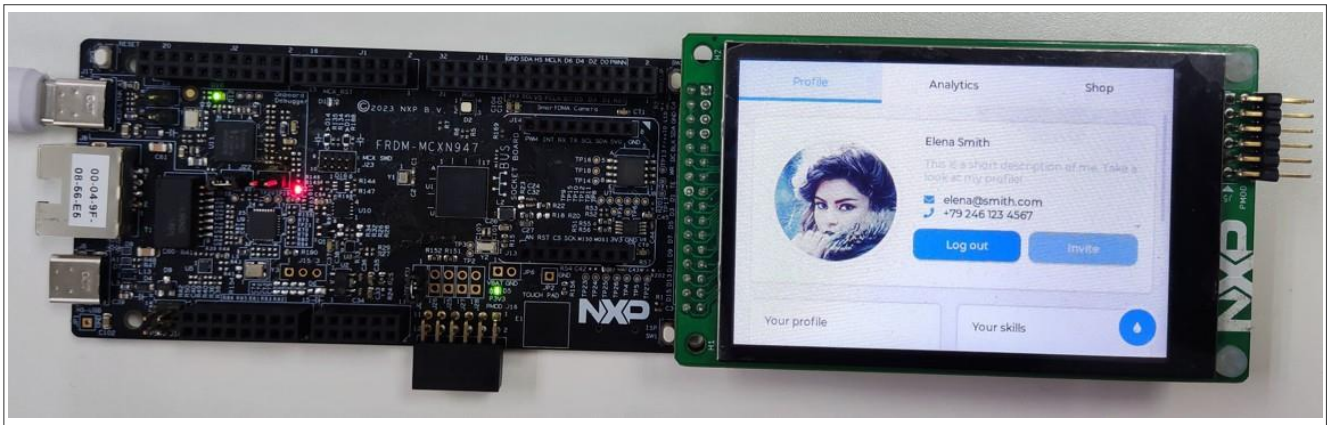

图2. LVGL窗口组件演示

7 基于FRDM-MCXN236的演示介绍

下载MCX N MCU最新的SDK。打开示例`lvgl_demo_widgets_bm`的路径。根路径为：`\boards\frdmmcxn236\lvgl_examples\lvgl_demo_widgets_bm`。

该工程主要演示了LVGL窗口组件的功能。通过使用FlexIO来模拟MCU8080接口实现了显示驱动程序。SmartDMA协助FlexIO将数据从RAM传输到数据寄存器。

图3所示为MCUXpresso工程。

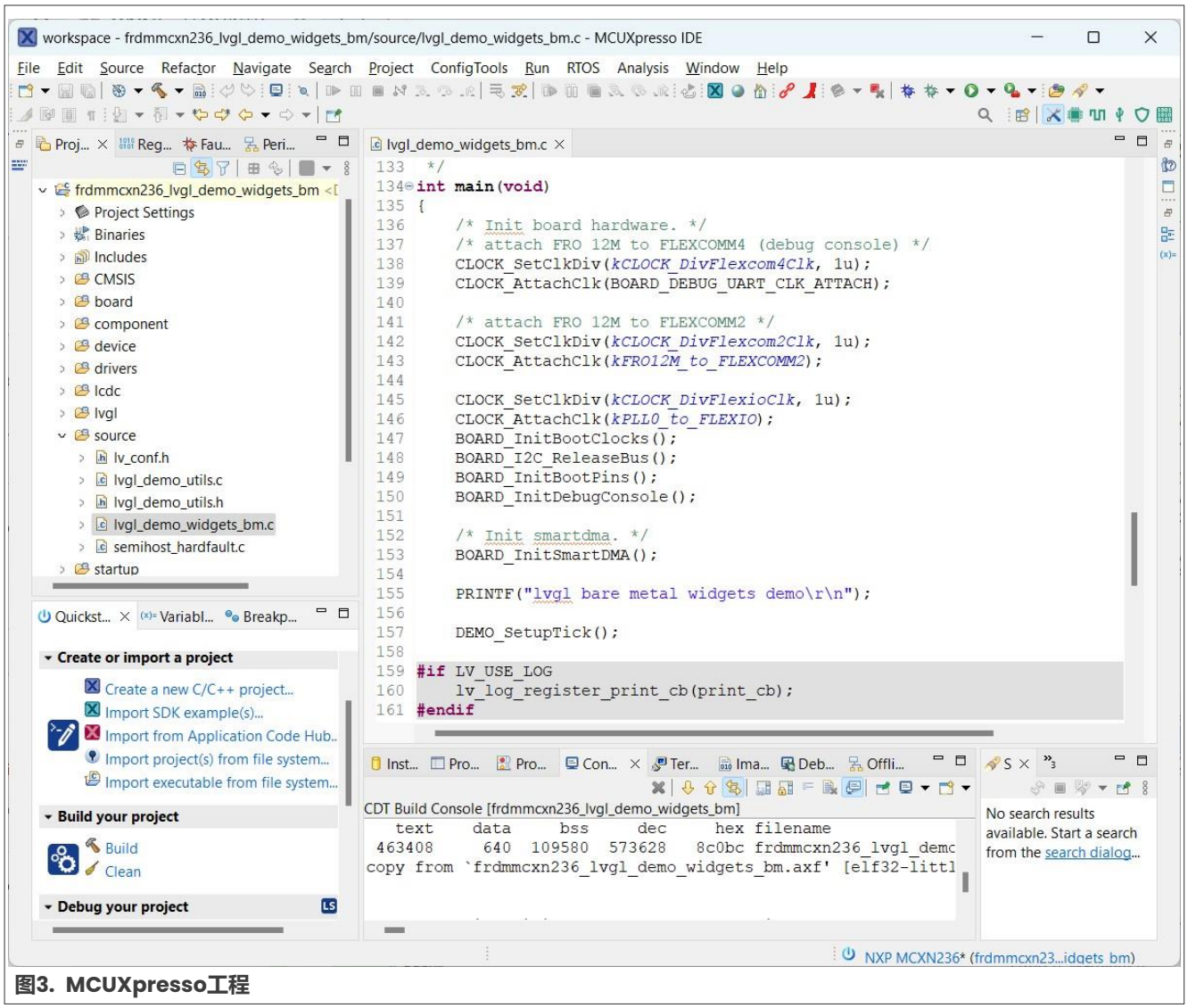

图3. MCUXpresso工程

为了展示SmartDMA的通用DMA功能，请执行以下步骤：

1. 将USB电缆连接至计算机和FRDM-MCXN236的端口J10。
2. 编译并下载代码。
3. 按下Reset按钮，代码开始运行。
4. 屏幕上将显示LVGL窗口组件演示的运行情况。

图4展示了演示结果。

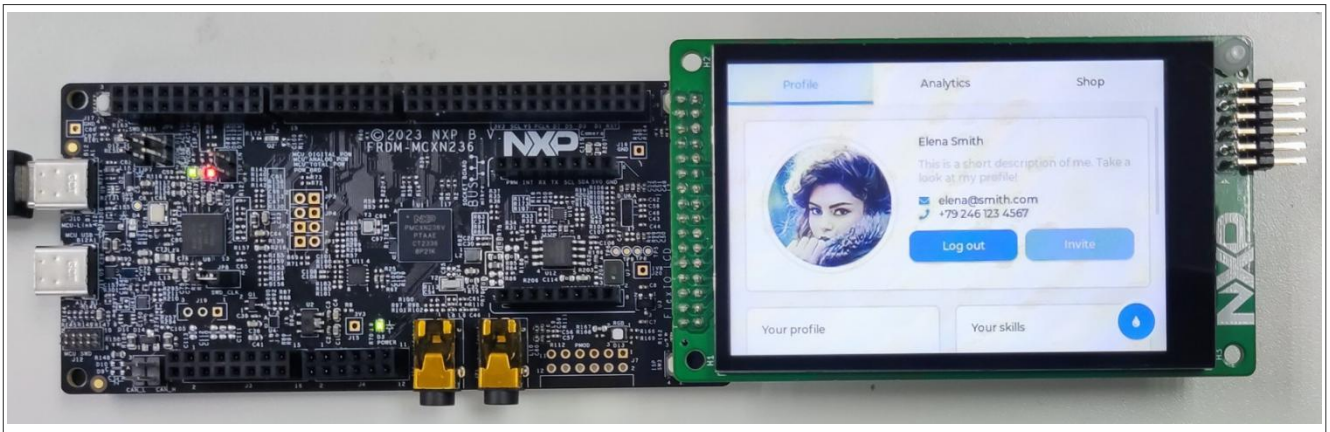

图4. 演示结果

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9 修订历史

表2总结了本文的修订情况。

表2. 修订历史

文档ID	发布日期	说明
AN14172 v.2.0	2024年5月6日	• 更新了第6节 • 添加了第7节
AN14172 v.1.0	2024年1月20日	首次公开发布

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