INTRODUCTION

Medical syringe pumps are used to gradually administer small amounts of liquid medication to patients. Syringe pumps can save medical staff time and reduce errors for medications that need to be slowly pushed in at particular intervals of time, with specific flow rates and over the course of several minutes to several hours. Syringe pumps are also useful in microfluidic applications for chemical and biochemical research.

This application note describes the implementation of syringe pump demo with functional safety features and powered by the latest technology from Microchip.

The demo’s motor driver board features Microchip’s PIC16F1778 8-bit microcontroller (MCU), the MTS2916A motor driver, the LX3301A inductive sensor interface IC, the RN4871 Bluetooth® Low Energy module, and the MCP1703 LDO. This demo also utilizes Microchip’s PIC16 Class B Functional Safety Software Library.

The motor driver board connects to a 400 mm length motorized linear stage actuator assembly with a ball screw, a stepper motor, and a 3D-printed syringe barrel clamp (see Figure 1). The principle of this reference design can apply to various syringe pump applications from small handheld autoinjectors to full-size hospital syringe pumps.
BASIC FUNCTIONS OF SYRINGE PUMP DEMO DESIGN

Figure 2 illustrates the block diagram of the syringe pump demo. The demo has the following functions:

- PIC16 Class B Functional Safety Software Library
- Dual full-bridge PWM Motor driver capable of driving all types of stepper motors
- Detection of the brand and type of the syringe
- Detection of fluid volume of the syringe
- Input and output interface of user
- Bluetooth Low Energy connectivity

FIGURE 2: FUNCTIONAL BLOCK DIAGRAM
CLASS B FUNCTIONAL SAFETY SOFTWARE LIBRARY

Ensuring the functional safety of medical devices is clearly critical for designers as these devices can impact the health of the patients that rely on them. Microchip has developed a library of low-level software routines that simplify meeting the IEC 60730 requirements for Class B Safety (see Appendix E: “References”).

Dedicated Core Independent Peripherals (CIPs) and functions have been integrated into Microchip’s microcontrollers (MCUs) to help increase the reliability and monitoring for safety-critical applications. Designers can choose proper MCUs with functional safety libraries to tackle the range of standards for compliance.

Together, these hardware and software features help ensure that end applications operate as intended, with a safe shutdown if any exception or issue arises. Figure 3 shows the demo’s firmware flowchart with specific 8-bit PIC16 Class B Safety Software Library routines including:

- CLASSB_RAMMarchBTest() – for testing the RAM memory using March B algorithm
- CLASSB_CPURegisterTest() – for testing the CPU registers
- CLASSB_CPUPCTest() – for testing the CPU program counter
- CLASSB_CRCFlashTest(...) – for testing the flash memory using the Cyclic Redundancy Check (CRC)

FIGURE 3: SYRINGE PUMP DEMO FUNCTIONAL SAFETY FIRMWARE FLOWCHART

Together, these hardware and software features help ensure that end applications operate as intended, with a safe shutdown if any exception or issue arises. Figure 3 shows the demo’s firmware flowchart with specific 8-bit PIC16 Class B Safety Software Library routines including:

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- CLASSB_CPUPCTest() – for testing the CPU program counter
- CLASSB_CRCFlashTest(...) – for testing the flash memory using the Cyclic Redundancy Check (CRC)
INDUCTIVE SENSOR INTERFACE IC
LX3301A

The installed plunger position and barrel diameter of the syringe are two important data to be monitored continuously. Such data can be used to calculate the injecting volume and to determine whether a correct syringe is installed. The syringe pump demo uses Microchip’s LX3301AEVB14L (linear sensor interface, as shown in Figure 4) and the LX3301AEVB14R (rotary sensor interface, as shown in Figure 4) inductive position sensor system evaluation kits (see Appendix E: “References”) to respectively measure the linear position of the installed plunger and the rotary position (diameter) of the installed barrel of the syringe.

The LX3301AEVB14 series of boards consists of low-cost, high-resolution linear, and rotary position sensor system evaluation kits. The sensor system consists of the LX3301AQPW inductive sensor measurement integrated circuit (IC) and its linear or rotary inductive printed circuit board (PCB) sensor. A target PCB attached to a movable mechanical housing provides position sensing relative to the fixed linear or rotary inductive PCB. The LX3301AEVB14 series demonstrates the capability of LX3301AQPQW inductive sensor smart interface in sensing the presence and position of a conductive target.

The LX3301AQPW IC contains an internal EEPROM for storing calibration and configuration parameters. The calibration parameters enable the production sensor assembly to be factory-calibrated, guaranteeing consistent unit-to-unit performance. The configuration parameters enable the LX3301AQPW measurement IC to be used in multiple sensor applications.

FIGURE 4: LX3301A ROTARY AND LINEAR EVALUATION BOARDS

[Image of LX3301A evaluation boards]
The plunger of the installed syringe can be pushed or pulled by using a linear stage actuator, in which the actuator is motorized by a stepper motor. The core operation of the syringe pump is to precisely control the motor in order to inject the right amount of medication into the patient. The MTS2916A motor driver is a CMOS device capable of driving both windings of a bipolar stepper motor or bidirectionally controlling two DC motors. Each of the two independent H-bridge outputs is capable of sustaining 40V and delivering up to 750 mA of continuous current. Therefore, the motor driver circuit design of this demo can be applied to various types of motors depending on the customers' applications.

The MTS2916A control modes consist of full-step, half-step, modified half-step, and micro-stepping control of the motor. Figure 5 shows one complete cycle of each stepping mode achievable with a typical application circuit.

A single Microchip MCU can provide all the control signals needed by each stepping mode of the MTS2916A, including PHASE 1 and 2, I01/I11 and I02/I12, and VREF 1 and 2 signals. In this syringe pump demo, the MTS2916A uses the Full-Step mode to control a NEMA 17 stepper motor. PHASE 1 and 2 logic inputs set the direction of current flow through the load to change the motor spin direction. I0 and I1 are set to 00 so that the output current of MTS2916A I_{MAX} = \frac{V_{REF}}{10R_s}, where V_{REF} = 1.94V and R_s = 1R. When I0 = I1 = 11, no current flows through the load and the motor is turned off.
MICROCONTROLLER PIC16F1778

The PIC16F1778 microcontroller (MCU) features high-level integration of intelligent analog and digital peripherals for a wide range of applications. The MCU’s two internal 10-bit Digital-to-Analog Converters (DACs) connecting with two internal Operational Amplifiers (OPAs) provide two adjustable and buffered voltage references for the MTS2916A’s VREF1 and VREF2 input pins.

The syringe pump demo offers two methods to drive the PHASE 1 and 2 signals of the MTS2916A. The first method is to have two Configurable Logic Cells (CLCs) and two 10-bit Pulse-Width Modulation (PWM) modules work together to generate two different PWM signals for driving the MTS2916A’s PHASE 1 and PHASE 2. In this demo, the output of PWM5 is setup as the input of CLC3 and the output of PWM6 is setup as the input of CLC4. Then the PWM signals are AND-OR’ed to the specific output pin for each CLC (CLC3OUT/RB2/PHASE1 and CLC4OUT/RB5/PHASE2) as shown in Figure 6. The CLC and PWM models are Core Independent Peripherals (CIPs) that are integrated into the PIC16F1778 MCU. The demo firmware initially configures the CIPs and enables the output to the motor driver. After that, the motor driver operation requires no firmware interaction due to the capabilities of the CIPs.

The second method is to use the I/O ports (RB2/PHASE1 and RB5/PHASE2) to toggle the PHASE 1 and 2 signals to complete each full stepping cycle. This method may be easy to set up, but it requires the supervision of the firmware. Customers can decide which method is best suited for their applications.

The PIC16F1778’s Analog-to-Digital Converter (ADC) continuously monitors the analog signals coming from two LX3301A inductive sensors to monitor the diameter of the installed syringe and the position of the installed plunger of the syringe. The brand information of the installed syringe can be determined based on the rotary position (diameter). For example, when the MCU detected a BD-10 ml syringe being installed, it could check a preprogrammed database to determine whether it was the correct syringe type for the selected medication. The injection volume can be calculated combining the rotary data and the linear data sent back from the two LX3301A inductive sensors. The demo will display alert messages, set off an audible alarm, and shut off the motor when any preset limits (such as the full, empty, or diameter limits of the syringe) are reached in the rotary direction or in the linear direction.

FIGURE 6: EXAMPLE OF CLC3 CONFIGURATION IN AND-OR MODE WITH PWM5 AS INPUT

The Serial Peripheral Interface (SPI) module is used to send information, such as the real-time syringe volume or user messages, to an OLED display panel. The UART module is used to communicate with the RN4871 Bluetooth Low Energy module.

To ensure safe operation of the syringe pump, some of the important components of the PIC16F1778 MCU, such as CPU registers, CPU program counter and memories, are periodically checked by calling the PIC16 Class B Functional Safety software routines at start-up or during run time. Should any faults be detected, the software will place the MCU and entire system into Safe mode, and then shut off the pump and set off an alarm.
BLUETOOTH LOW ENERGY MODULE RN4871

The RN4871 is a small form factor Bluetooth Low Energy (BLE) module, which has a completely integrated Bluetooth software stack and offers a shielded regulatory certified radio with built-in antenna. This module is perfect for IoT (Internet of Things) applications when interfaced to a BLE-enabled smartphone or Bluetooth Internet Gateway. Applications can be monitored, controlled, and updated from anywhere in the world.

The Microchip Bluetooth Data (MBD) mobile application is available to speed up development for both Android and iOS (see Appendix E: "References" for free download links). The syringe pump demo can send user information, such as real-time syringe volume or alert messages, to the MBD mobile application. Users can also remotely turn on/tum off the motor using the MBD mobile application. Figure 7 shows the MBD application monitoring and controlling the syringe pump demo using the BM70 support section of the application.

**FIGURE 7: MBD APPLICATION COMMUNICATING WITH THE SYRINGE PUMP DEMO**
APPENDIX A: SYRINGE PUMP DEMO BOARD

FIGURE 8: SYRINGE PUMP DEMO BOARD (TOP VIEW)

FIGURE 9: SYRINGE PUMP DEMO BOARD (BOTTOM VIEW)
### APPENDIX C: SYRINGE PUMP DEMO BOARD BILL OF MATERIALS (BOM)

#### TABLE 1: SYRINGE PUMP DEMO BOARD BOM

<table>
<thead>
<tr>
<th>Designator</th>
<th>Description</th>
<th>Part Number</th>
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</thead>
<tbody>
<tr>
<td>C1, C2</td>
<td>Capacitor 1 uF 50V 1206</td>
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<tr>
<td>C3, C4</td>
<td>Capacitor 1 uF 16V 0805</td>
<td>N/A</td>
</tr>
<tr>
<td>C5, C6, C7, C8, C9, C23, C24</td>
<td>Capacitor 0.1 uF 16V 0603</td>
<td>N/A</td>
</tr>
<tr>
<td>C10</td>
<td>Capacitor 0.01 uF 25V 0603</td>
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</tr>
<tr>
<td>C11, C12, C13, C14</td>
<td>Capacitor 1000 pF 50V 0603</td>
<td>N/A</td>
</tr>
<tr>
<td>C15</td>
<td>Capacitor 0.1 uF 50V 0805</td>
<td>N/A</td>
</tr>
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<td>C16</td>
<td>Capacitor 100 uF 50V D8</td>
<td>N/A</td>
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<tr>
<td>C17, C18, C19, C20</td>
<td>Capacitor 1 uF 16V 0603</td>
<td>N/A</td>
</tr>
<tr>
<td>C21, C22</td>
<td>Capacitor 2.2 uF 10V 0603</td>
<td>N/A</td>
</tr>
<tr>
<td>D1</td>
<td>Diode Rectifier S1A-E3/61T</td>
<td>S1A-E3/61T</td>
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<tr>
<td>D2</td>
<td>LED GREEN 2V 30 mA 44.5 mcd clear 1206</td>
<td>N/A</td>
</tr>
<tr>
<td>D3</td>
<td>LED BLUE 3.2V 20 mA 140 mcd clear 1206</td>
<td>N/A</td>
</tr>
<tr>
<td>D4</td>
<td>LED RED 2.2V 20 mA 40 mcd clear 0805</td>
<td>N/A</td>
</tr>
<tr>
<td>J1</td>
<td>CON POWER 2.5 mm 5.5 mm switch slotted TH R/A</td>
<td>PJ-J002B</td>
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<tr>
<td>J2</td>
<td>CON HDR 2.54 Female 1x4 Gold 6.6 MH SMD RA</td>
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<tr>
<td>J3, J4</td>
<td>CON HDR 1.25 Male 1x4 Shroud SMD R/A</td>
<td>WM7622CT-ND</td>
</tr>
<tr>
<td>J5, J6, J7, J8</td>
<td>CON HDR 2.54 Male 1x25 5.84 MH TH VERT</td>
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</tr>
<tr>
<td>J9</td>
<td>CON HDR 2.54 Male 1x4 Gold 5.4 MH SMD R/A</td>
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<td>LCD1</td>
<td>Display OLED OSC-2864HSWEG01</td>
<td>OSC-2864HSWEG01</td>
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<td>R1, R2, R3, R4, R5, R6, R7</td>
<td>Resistor TKF 470R 1% 1/10W SMD 0603</td>
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<tr>
<td>R8, R9, R10, R11</td>
<td>Resistor TF 10K 1% 1/16W SMD 0603</td>
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<tr>
<td>R12, R13</td>
<td>Resistor TF 1k 0.1% 1/10W SMD 0603</td>
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<tr>
<td>R14, R15, R16, R17</td>
<td>Resistor TF 2k 0.1% 1/10W SMD 0603</td>
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<tr>
<td>R18, R19</td>
<td>Resistor TKF 1R 1% 3/4W SMD 2010</td>
<td>N/A</td>
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<tr>
<td>R20, R21</td>
<td>Resistor TKF 22k 1% 1/10W SMD 0603</td>
<td>N/A</td>
</tr>
<tr>
<td>R22</td>
<td>Resistor TKF 390k 1% 1/10W SMD 0603</td>
<td>N/A</td>
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<tr>
<td>R23</td>
<td>Resistor TKF 100R 5% 1/10W SMD 0603</td>
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</tr>
<tr>
<td>S1</td>
<td>Switch Slide SPDT 200 MA 12V SMD</td>
<td>CL-SB-12B-01T</td>
</tr>
<tr>
<td>S2, S3, S4, S5</td>
<td>Switch Tact SPST 12V 50 mA SMD</td>
<td>TL3302AF180QJ</td>
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<tr>
<td>BZ1</td>
<td>Buzzer Audio Piezo 25V SMD</td>
<td>CMT-1603</td>
</tr>
<tr>
<td>U1</td>
<td>MCU PIC16F1778-E/SS SSOP-28</td>
<td>PIC16F1778-E/SS</td>
</tr>
<tr>
<td>U2</td>
<td>Motor Driver MTS2916ALGC1 SOP-24</td>
<td>MTS2916A-LGC1</td>
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<tr>
<td>U3</td>
<td>LDO 5V MCP1703T-5002E/CB SOT-23-3</td>
<td>MCP1703T-5002E/CB</td>
</tr>
<tr>
<td>U4</td>
<td>LDO 3.3V MCP1703T-3302E/CB SOT-23-3</td>
<td>MCP1703T-3302E/CB</td>
</tr>
<tr>
<td>U5</td>
<td>Bluetooth Low Energy Module RN4871-I/RM128</td>
<td>RN4871-I/RM128</td>
</tr>
<tr>
<td>U6</td>
<td>CRYPTO AUTH ATECC608A-MAHDA-T UDFN-8</td>
<td>ATECC608A-MAHDA-T</td>
</tr>
<tr>
<td>M1</td>
<td>400 mm length linear stage actuator assembly with ball screw and stepper motor</td>
<td>CBX1605-400A</td>
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</tbody>
</table>
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APPENDIX E: REFERENCES

• Microchip’s Functional Safety products: https://www.microchip.com/design-centers/functional-safety


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