MOUNT VERNON
NAZARENE UNIVERSITY

STORM
Lab

Antenna Design for Contact Lens Mounted Sensors using NFC

Caleb Syler, Owen Paulus

Advisor:

Dr. Yuan “Edward” Meng
STORM Lab, Engineering Department, MVNU

Introduction

The eye motion has been demonstrated as a potential surrogate for the brain motion during the first 20 milliseconds after the impact on the head in a single direction, utilizing wired inertial sensors by the advisor. However, wired systems cannot be worn in the eye in the field, thus a fully wireless wearable system is to be created. A non-invasive wearable wireless multimodal sensor system consisting of a contact lens with an NFC coil antenna has been designed and fabricated for the purpose.

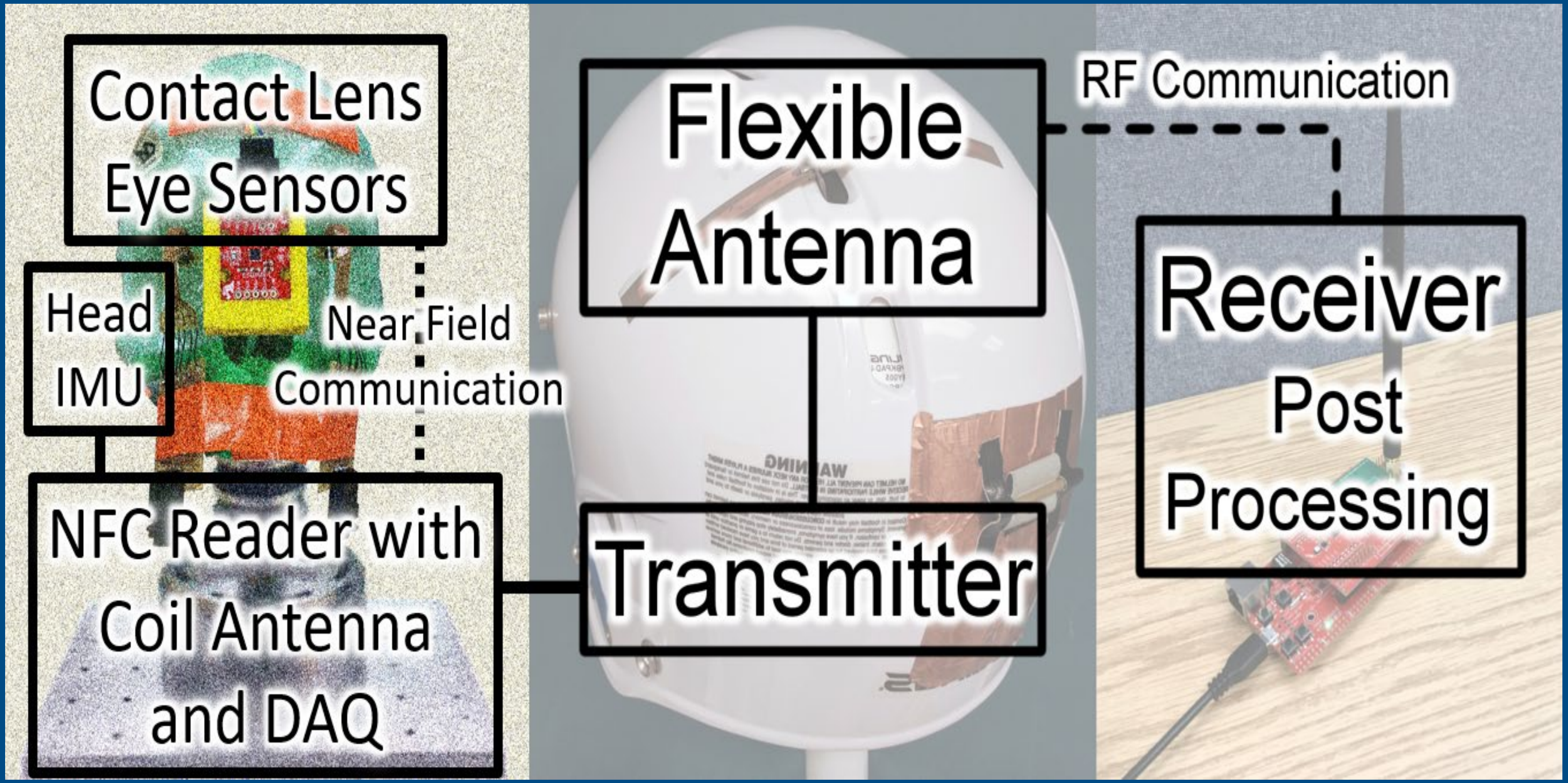

Fig. 1. A systematic view of the wireless sensing system for real-time objective concussion diagnosis.

Introduction

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Fig. 2. The concept of wireless sensing system on a contact lens for real-time objective concussion diagnosis.

Theoretical Basis

NFC is a set of communication protocols that enables communication between two electronic devices over a distance of 4 cm or less, using a frequency of 13.56 MHz and a data rate up to 106 kbit/s.

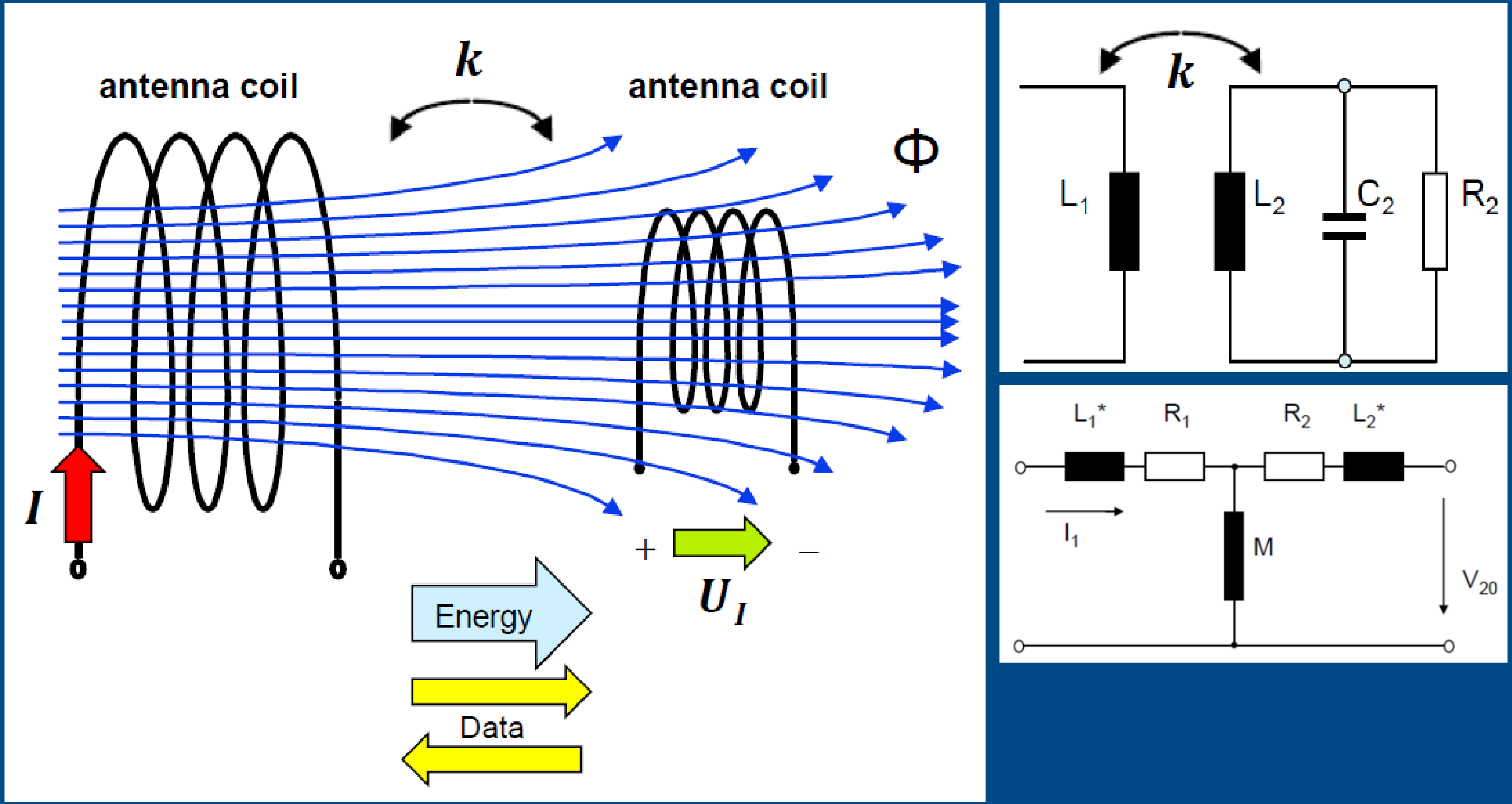


Fig. 3. Schematic diagrams for NFC data streaming, energy harvesting, and coupling coefficient.

Theoretical Basis

$$k = \mu \cdot \frac{r^2}{2\sqrt{(r^2 + x^2)^3}} \cdot \frac{A_2}{\sqrt{L_1 L_2}}$$

$$M = k \cdot \sqrt{L_1 \cdot L_2}$$

$$V_{20} = \omega \cdot M \cdot I_1$$

$\mu = permeability\ constant\ in\ certain\ material$

$r = antenna\ radius\ of\ reader\ coil$

$x = read\ range$

$A_2 = contact\ lens\ coil\ inner\ area$

$L_{1\ or\ 2} = self\ inductance$

Optimum antenna size: $r = x$

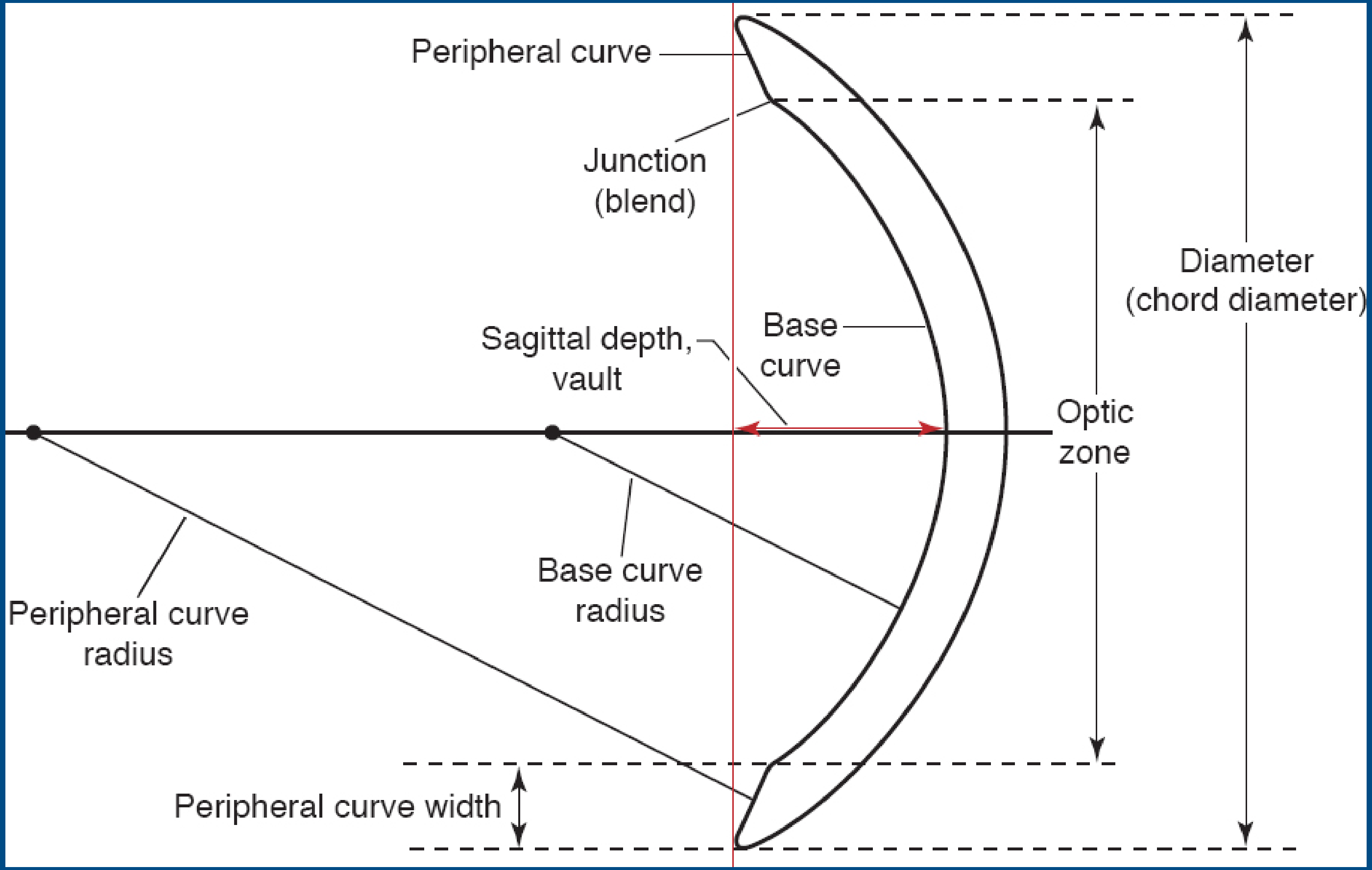


Fig. 4. A section view of a contact lens.

(Modified with permission from Stein HA, Freeman MI, Stein RM. CLAO Residents Contact Lens Curriculum Manual. *New Orleans: Contact Lens Association of Ophthalmologists; 1996. Redrawn by Christine Gralapp.)*

NFC Coil Antenna Design

Following Fig. 4, a contact lens with an NFC coil antenna was designed in SolidWorks^{TM} CAD. The CAD file was further used in 3D printing the prototypes of contact lens as shown in Fig. 7.

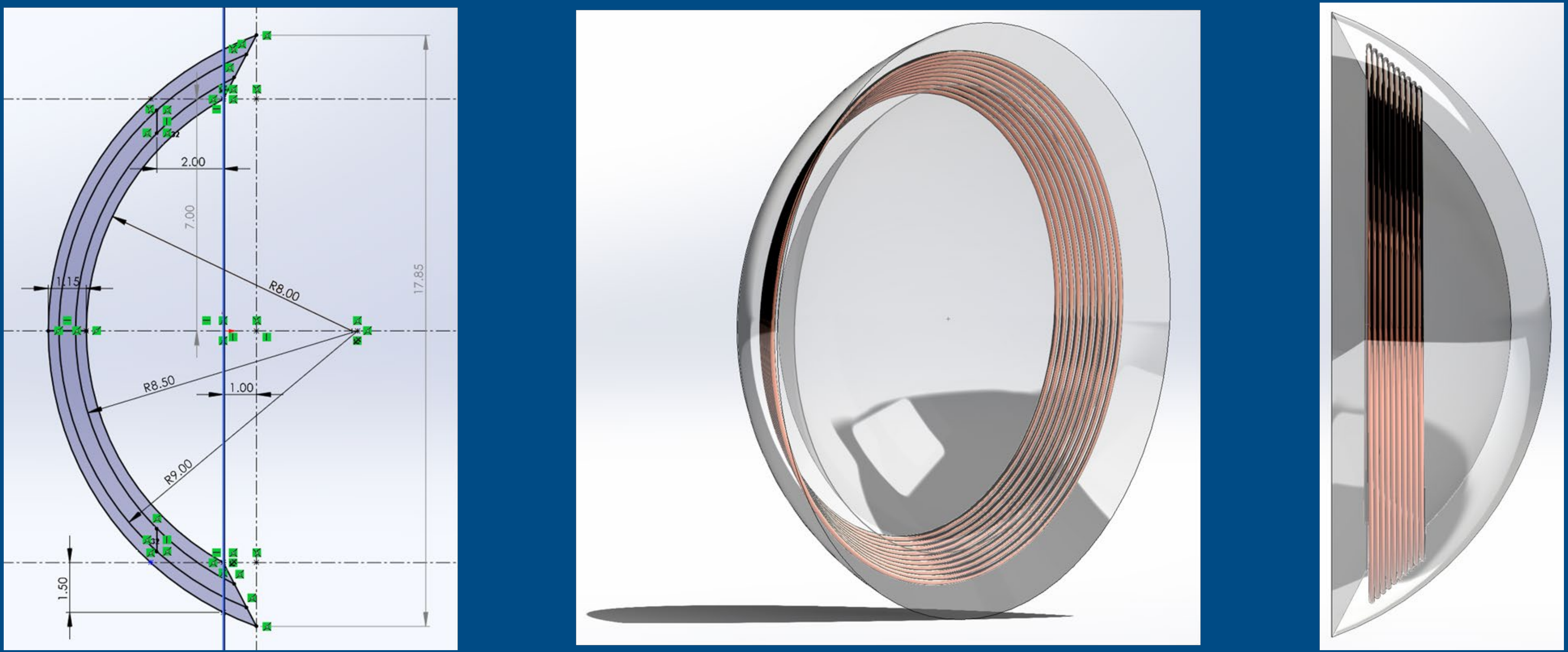
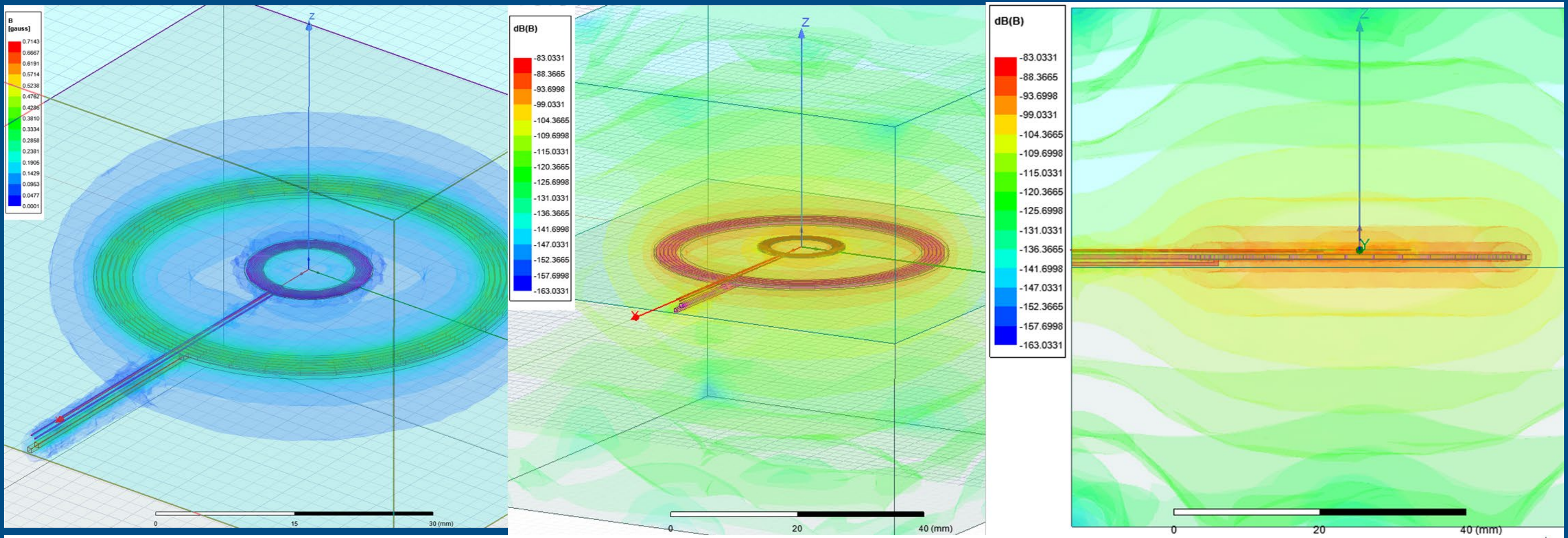
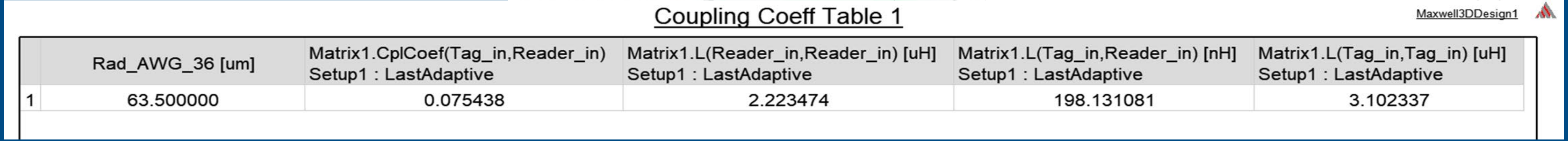


Fig. 5. NFC coil antenna design for a contact lens using SolidWorks^{TM} CAD. (a) a cross-section view of the contact lens design with dimensional details (in mm); (b) and (c) 3D models after rendering.

Simulation Results

The contact lens antenna (tag coil, 10 turns, AWG 36, excited by 5 mA) design in Fig. 5 was duplicated in ANSYS^{TM} Maxwell and simulated with an NFC reader antenna (5 turns, AWG 22, excited by 50 mA).





Coupling Coeff Table 1

Maxwell3DDesign1

	Rad_AWG_36 [um]	Matrix1.CplCoef(Tag_in,Reader_in) Setup1 : LastAdaptive	Matrix1.L(Reader_in,Reader_in) [uH] Setup1 : LastAdaptive	Matrix1.L(Tag_in,Reader_in) [nH] Setup1 : LastAdaptive	Matrix1.L(Tag_in,Tag_in) [uH] Setup1 : LastAdaptive
1	63.500000	0.075438	2.223474	198.131081	3.102337

Fig. 6. Simulation results for the electromagnetic fields between the reader and the tag coils from ANSYS^{TM} Maxwell. (a) B field in Gauss; (b) B field in dB; (c) a side view of the B field in dB.

NFC Coil Antenna Prototyping and Testing

The prototypes of the contact lens were 3D printed using transparent material. The resolution/quality was low. Better ones will be cast-molded using polydimethylsiloxane (PDMS). Testing results verified the self inductance of 3 µH (as in Table 1) and the resonant frequency of 13.56 MHz of the antenna as designed for the NFC protocols.

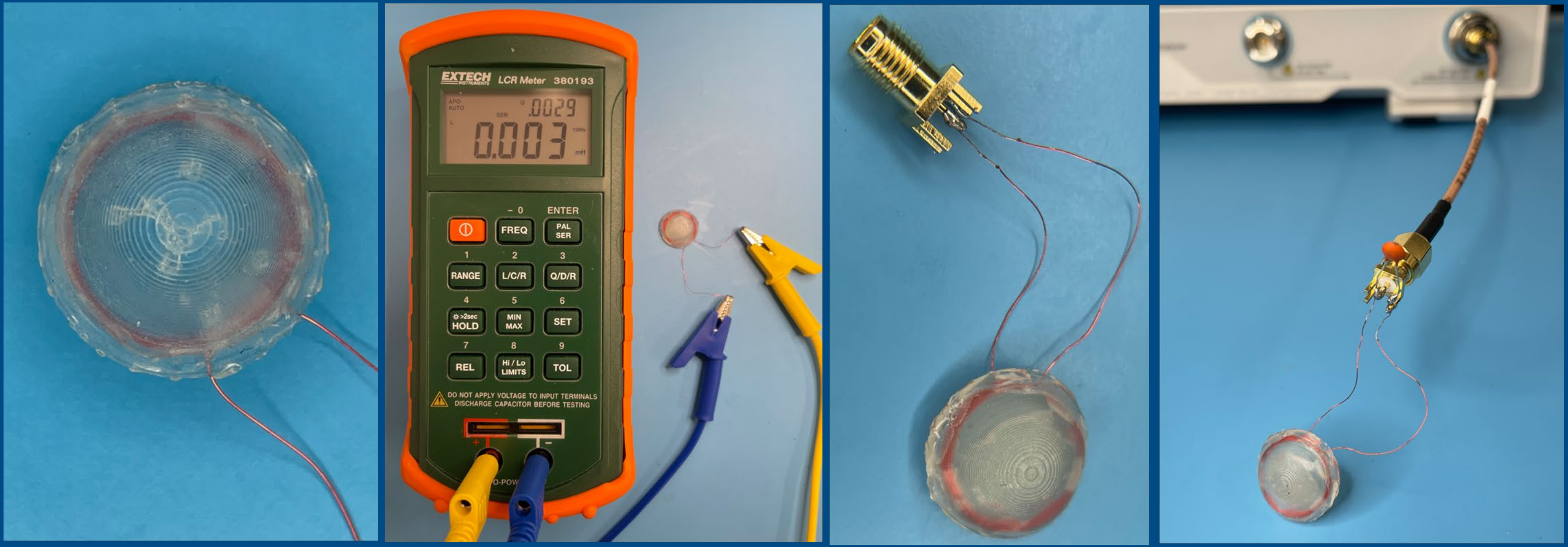


Fig. 8. A screenshot of the Rigol^{TM} real-time spectrum analyzer (RSA3015N), verifying the resonant frequency of ~13.56 MHz for NFC.

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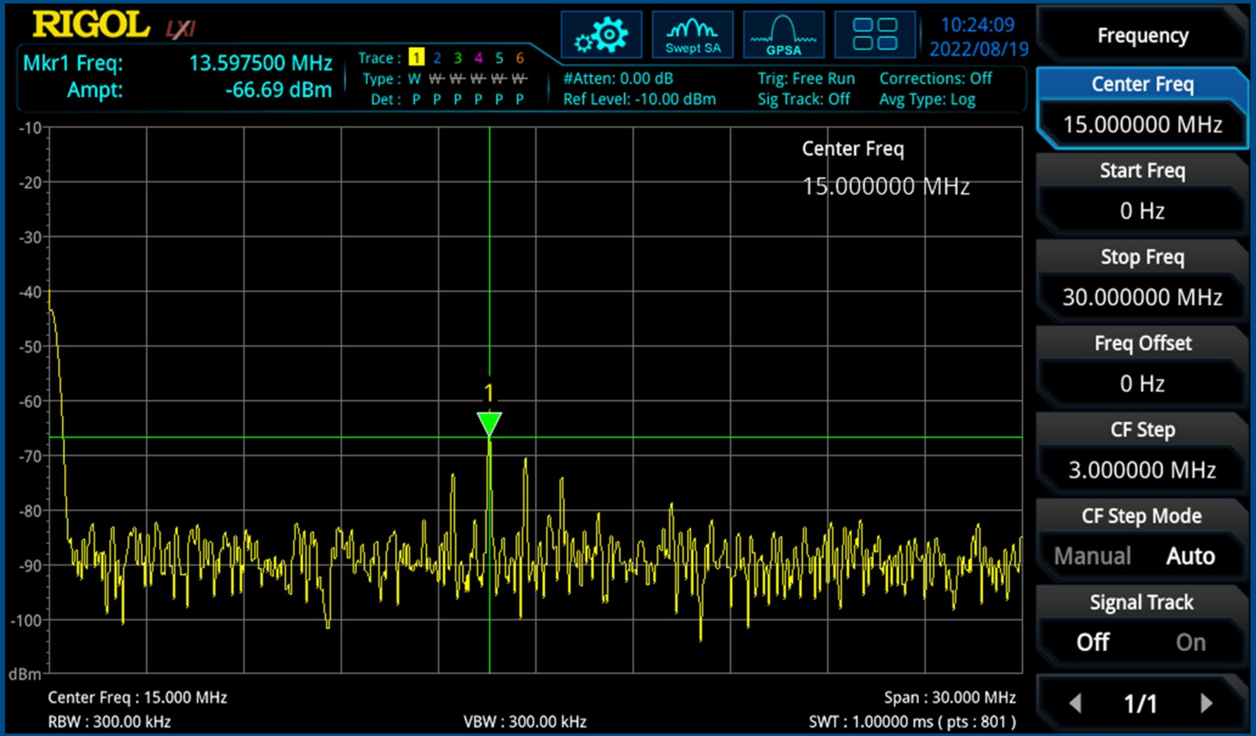

10:24:09
2022/08/19

Mkr1 Freq: 13.597500 MHz
Ampt: -66.69 dBm

Trace : 1 2 3 4 5 6
Type : W W W W W W
Det : P P P P P P

#Atten: 0.00 dB
Ref Level: -10.00 dBm
Trig: Free Run
Sig Track: Off
Corrections: Off
Avg Type: Log

Center Freq
15.000000 MHz

Center Freq : 15.000 MHz
RBW : 300.00 kHz
VBW : 300.00 kHz
Span : 30.000 MHz
SWT : 1.00000 ms (pts : 801)

Frequency
Center Freq: 15.000000 MHz
Start Freq: 0 Hz
Stop Freq: 30.000000 MHz
Freq Offset: 0 Hz
CF Step: 3.000000 MHz
CF Step Mode: Manual Auto
Signal Track: Off On
1/1

Fig. 8. A screenshot of the Rigol^{TM} real-time spectrum analyzer (RSA3015N), verifying the resonant frequency of ~13.56 MHz for NFC.

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PCB Design for Near Field Communication (NFC) Prototyping

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Advisor:

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STORM Lab, Engineering Department, MVNU

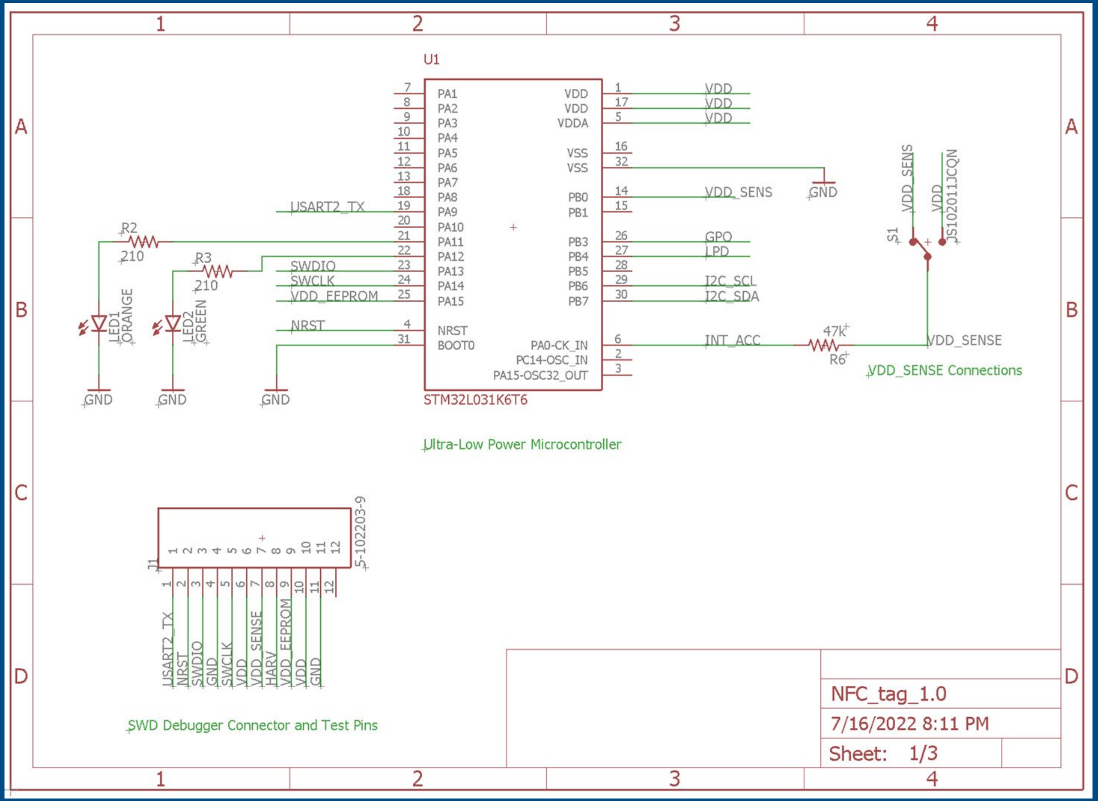
Introduction

Building circuits on a printed circuit board (PCB) brings a great number of advantages, including a compact design, the ease of testing and repair, lower assembly errors, avoiding short circuits, improved repeatability and reliability, and most importantly for the NFC prototyping, low noise and interface for radio frequency (RF) systems. Designing and prototyping on PCBs is thus a significant step towards building and miniaturizing the non-invasive wearable wireless multimodal sensor system for real-time objective concussion diagnosis.

Fig. 1. Near Field Communication (NFC).

Circuit Schematic Design

The PCB design of NFC_Tag_1.0 was performed on the EAGLE^{TM} CAD. The open-source documentation of STEVAL-SMARTAG1 evaluation board [1] was referred to for the circuit schematic design.



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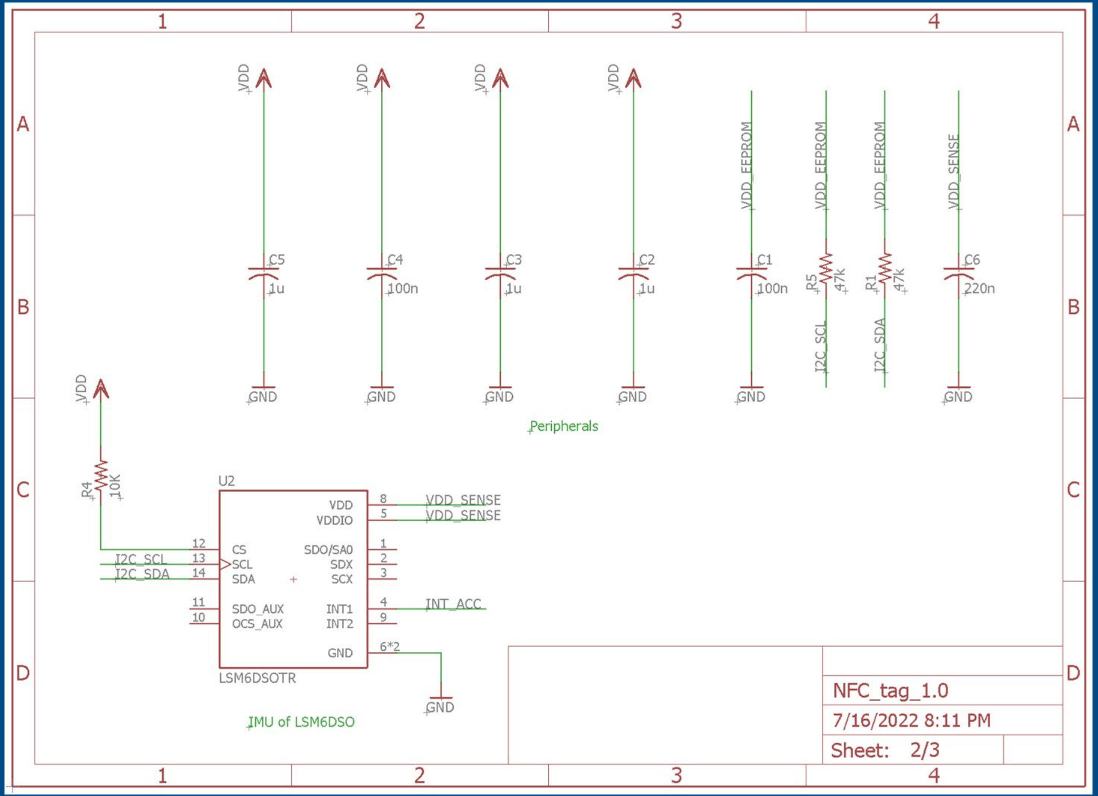

Fig. 3. Schematic sheet 2: inertial measurement unit (IMU, 6-DoF) and peripherals.

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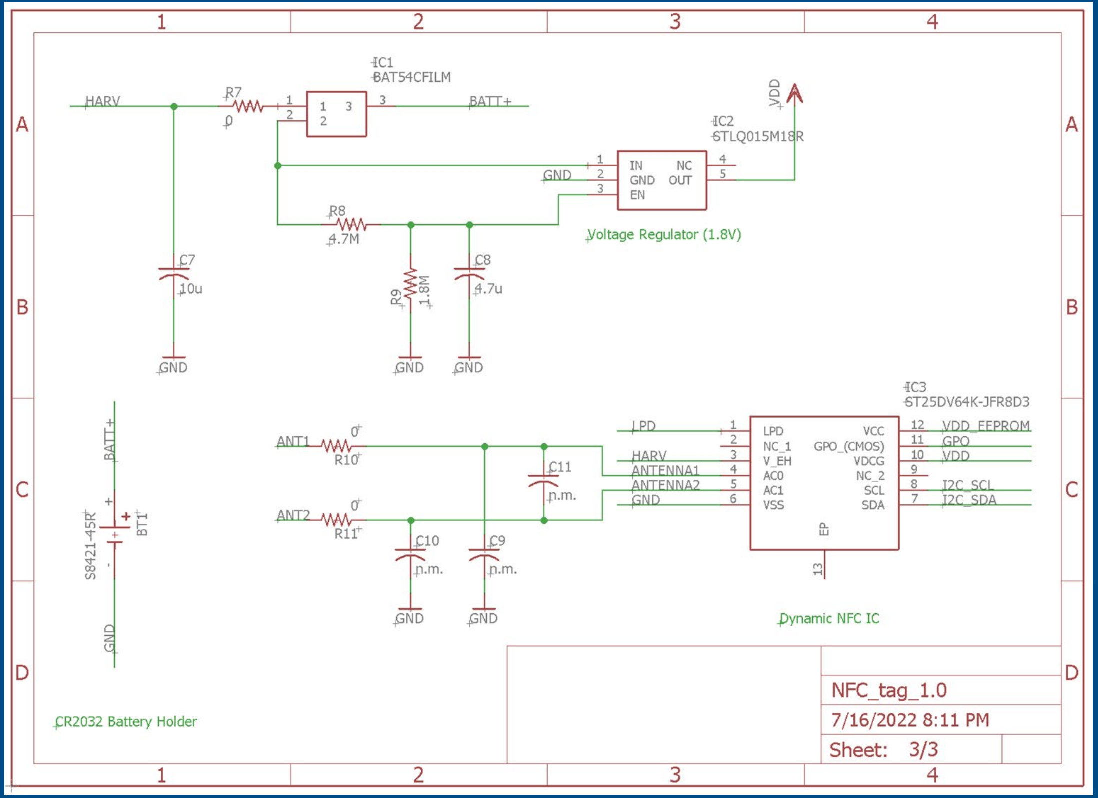


Fig. 4. Schematic sheet 3: dynamic NFC IC, voltage regulators, and battery holder.

PCB Layout Design

After the circuit schematic design was completed, the PCB layout design for a two-layer PCB was performed using EAGLE^{TM} CAD. Then Gerber files were generated for fabrication.

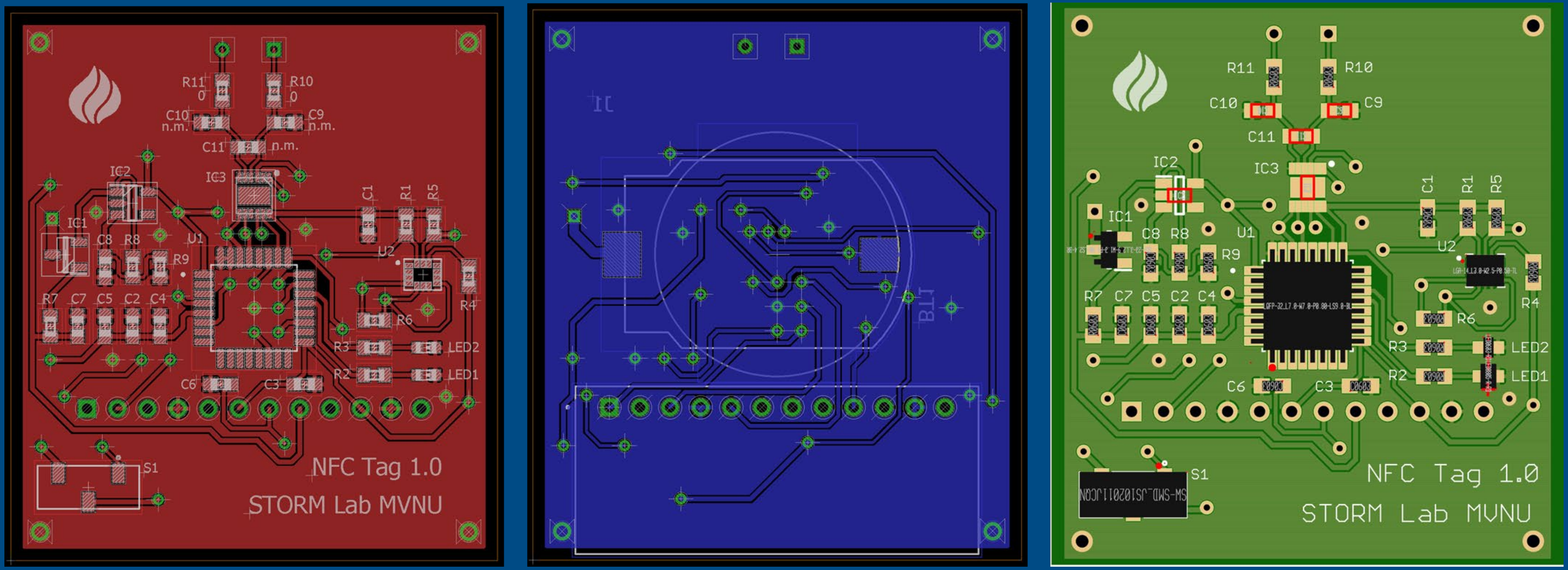
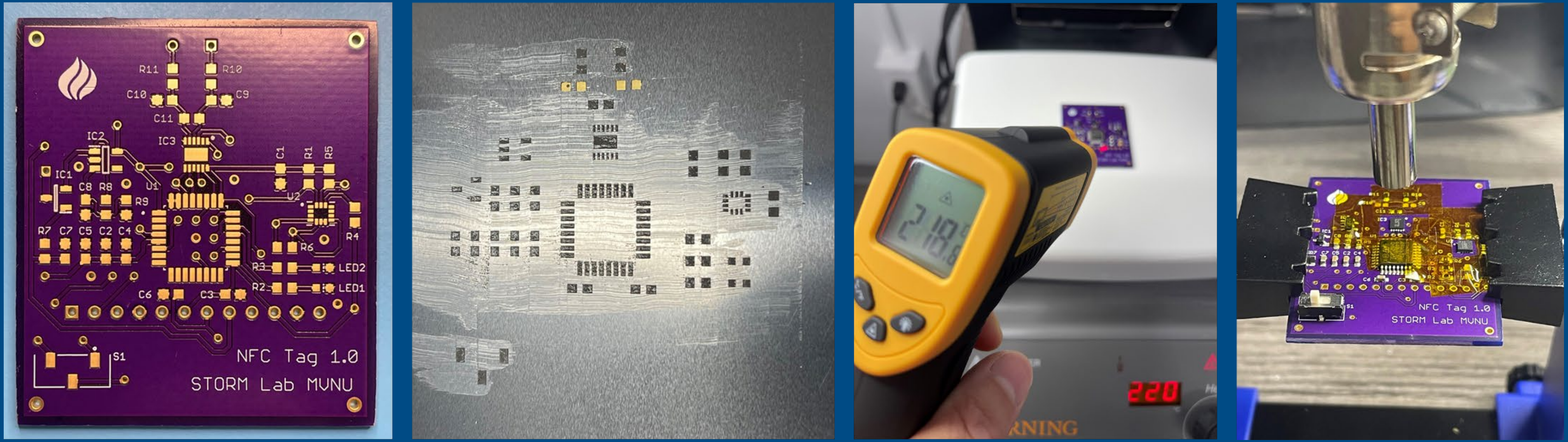


Fig. 4. Schematic sheet 3: dynamic NFC IC, voltage regulators, and battery holder.

PCB Fabrication and Assembly

Gerber files were sent to two PCB manufacturers, JLCPCB^{TM} and OSH Park^{TM}, for fabrication. JLCPCB^{TM} also partially assembled the components. A stencil for surface mount soldering was ordered from OSH Stencils^{TM} for easier replication of the assembly in house.



(a) (b) (c) (d)

Fig. 6. PCB assembly and reworking. (a) front side before soldering; (b) applying solder paste with a stencil; (c) reflow soldering on a hot plate; (d) reworking specific components with a hot air gun.

PCB Fabrication and Assembly

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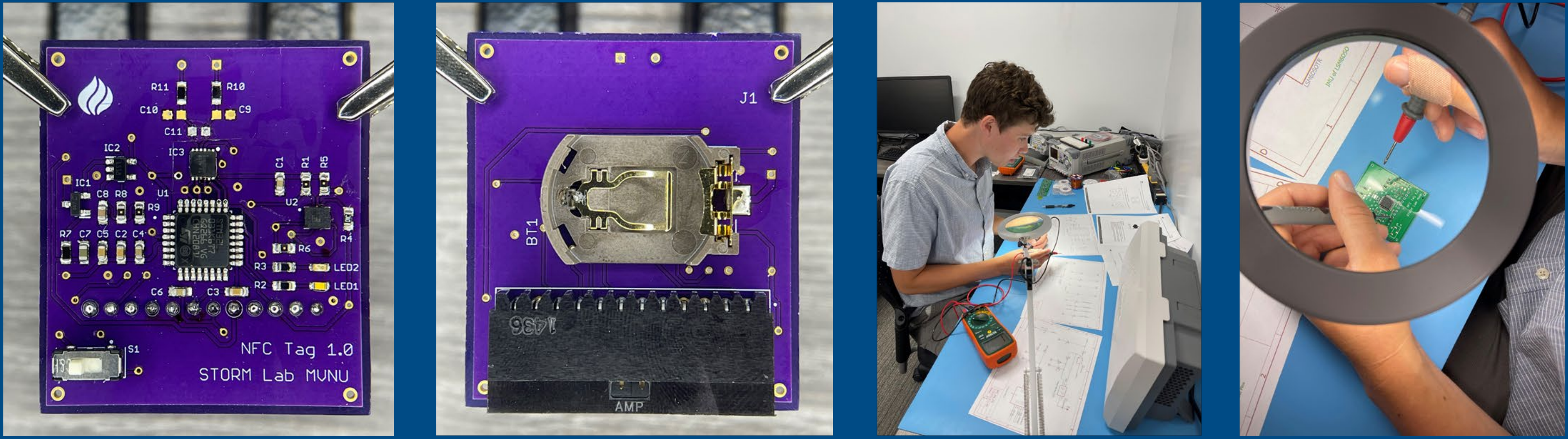
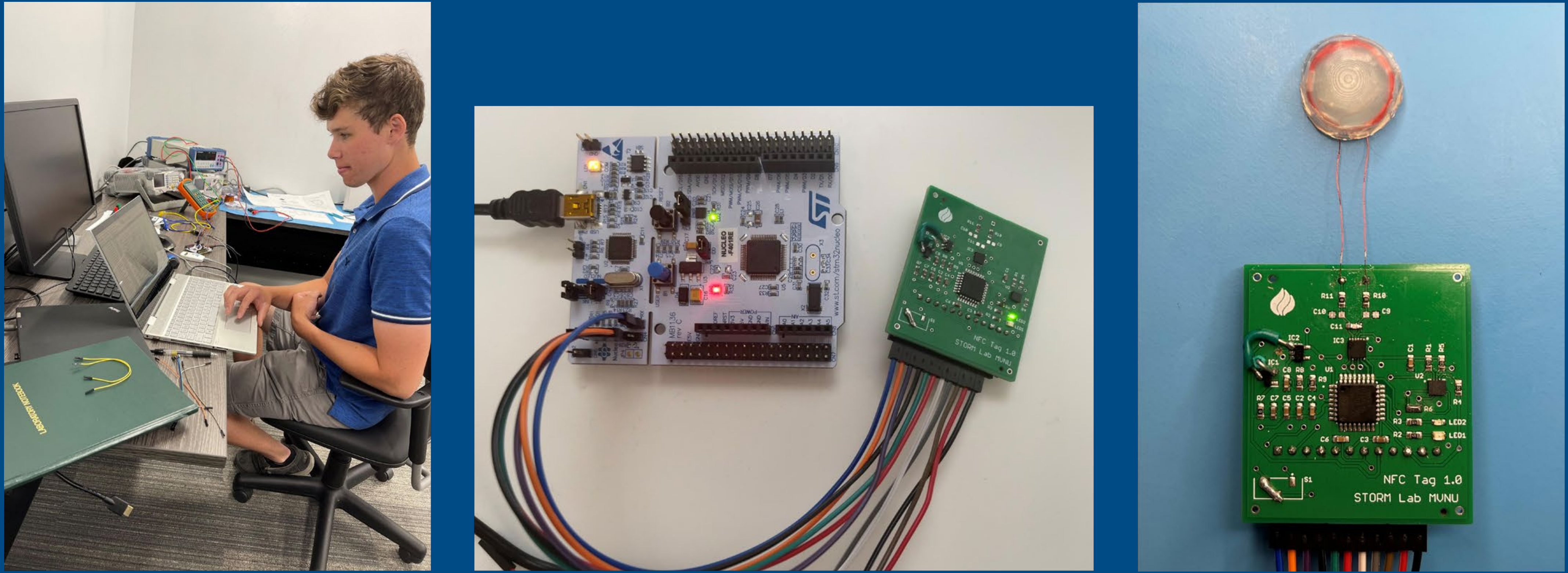


(a) (b) (c) (d)

Fig. 7. After assembly. (a) front side; (b) back side; (c) and (d) testing PCB.

Embedded Software Debugging

The embedded software programs developed during the Summer Project of Undergraduate Research 2022 were uploaded to and debugged on the microcontroller on the customized PCB. The flashing green LED in Fig. 8b indicates the success of the PCB prototyping.



(a)

(b)

(c)

Fig. 8. Debugging PCB. (a) uploading firmware to the microcontroller; (b) debugging PCB with SWD debugger on ST-NUCLEO board; (c) PCB with a contact lens antenna attached.

Future Work

For future work, more debugging of the embedded software will be performed on the PCB with the contact lens NFC coil antenna attached. IMU data will be streamed to an NFC reader wirelessly through NFC, stored on an SD card on the reader side, and processed on a PC.

References

[1] STMicroelectronics, “STEVAL-SMARTAG1: NFC Dynamic Tag sensor node evaluation board,”
URL: https://www.st.com/en/evaluation-tools/steval-smartag1.html.

Embedded Software Design for Wireless Sensing System on Contact Lens

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Introduction

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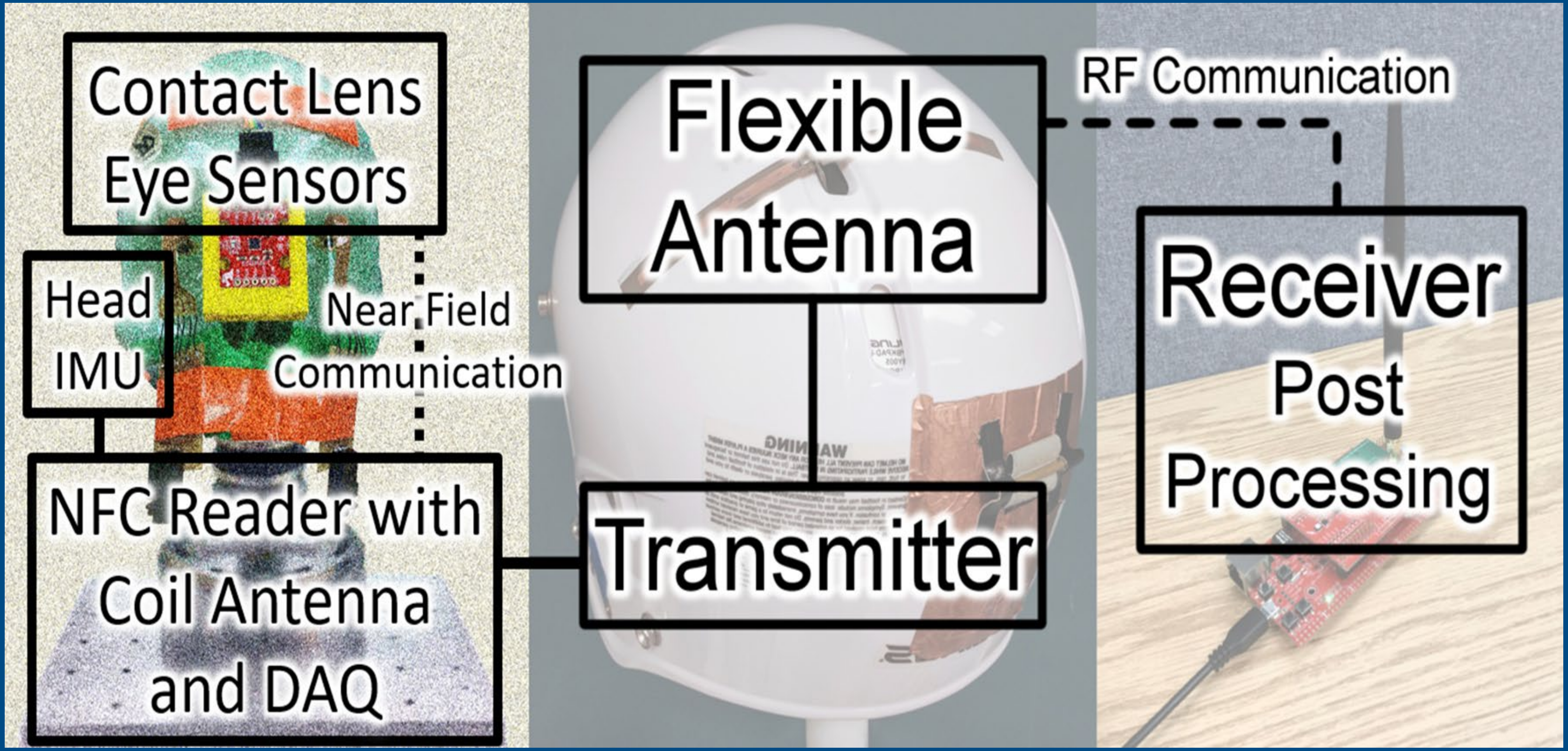


Fig. 1. A systematic view of the wireless sensing system for real-time objective concussion diagnosis.

System Overview

The systematic overview of the wireless sensing system on the contact lens using NFC technology, as boxed in red in Fig. 1, can be found in Fig. 2. In Fig. 2, the arrows with solid lines represent the flow of data, while the ones with dashed lines show the flow of energy.

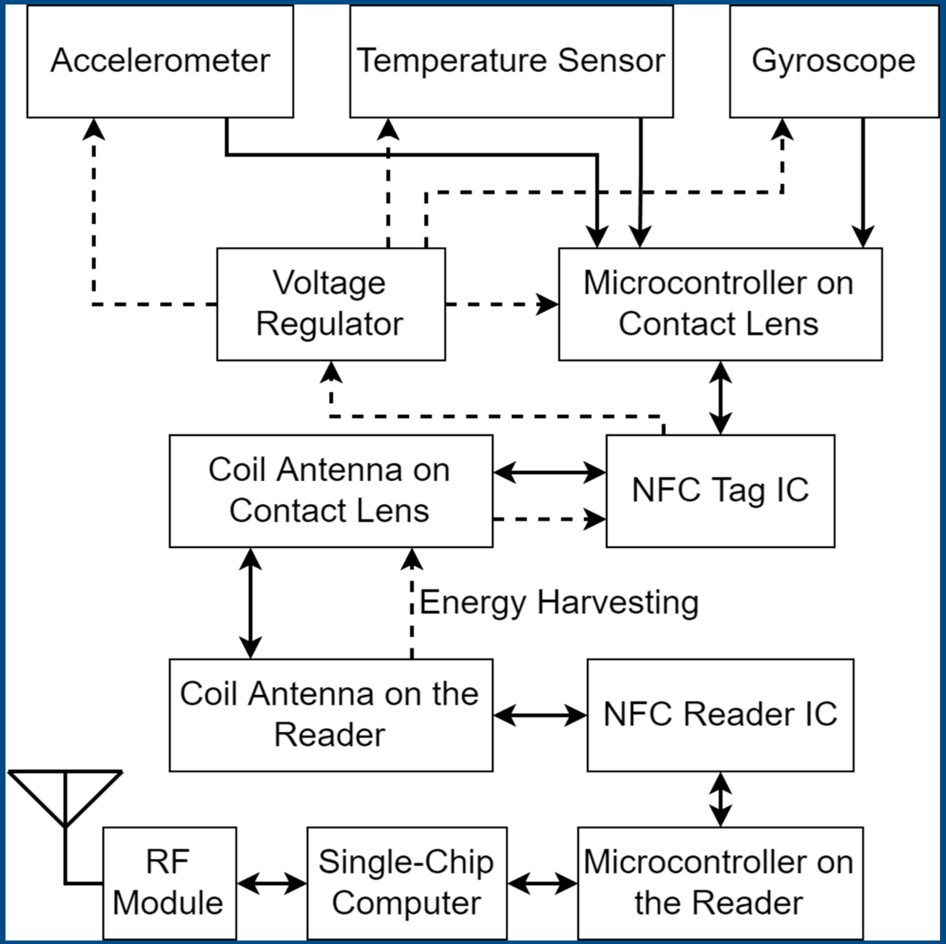


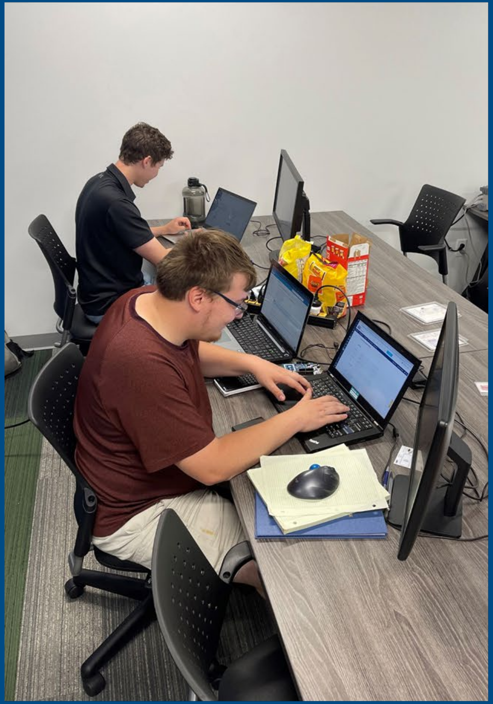
Fig. 2. A systematic view of the wireless sensing system on the contact lens (NFC tag) with an NFC reader.

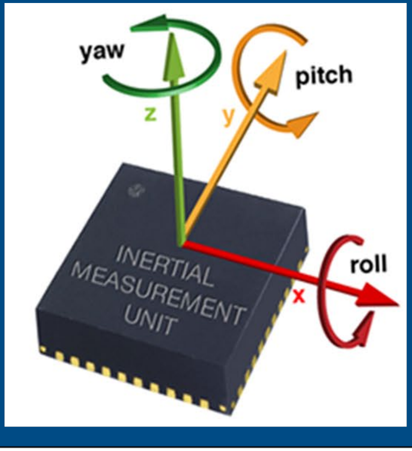
Developing on Breakout/Demo Boards

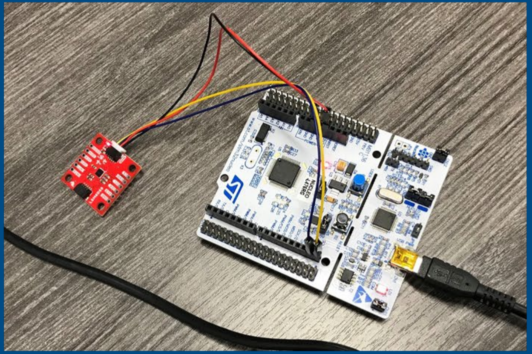
The development task of the embedded software was divided into two parts:

1. programming for data acquisition of the sensors (3-DoF Accelerometer, 3-DoF Gyroscope, and temperature sensor), and

2. programming for the near field communication (NFC).

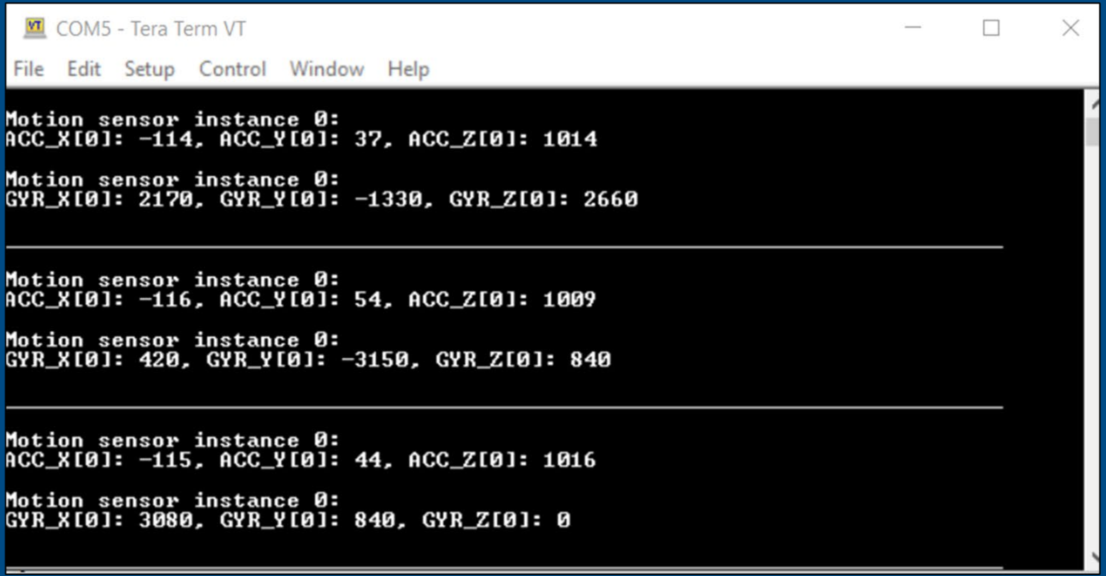






Gyroscope z-axis output (mdps)

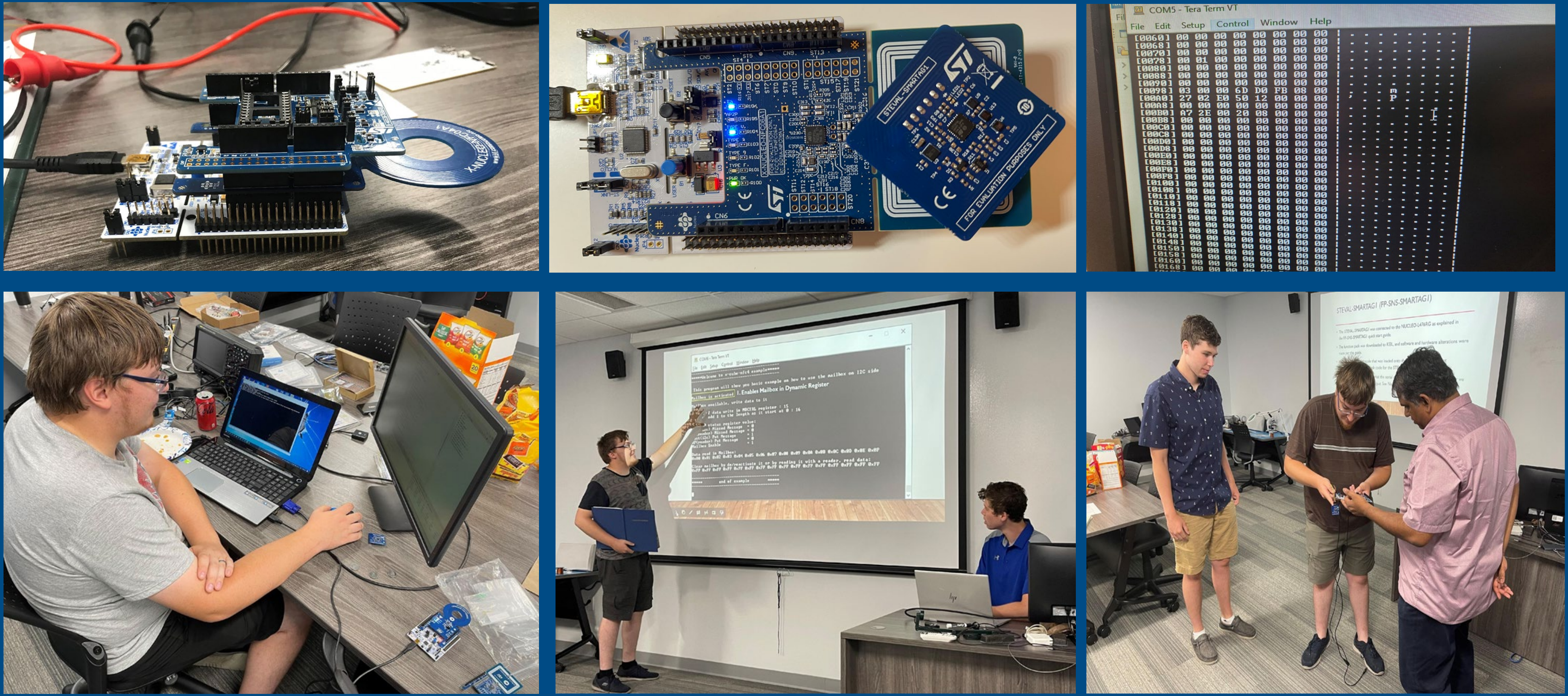
Accelerometer x-axis output (mG)



```
Motion sensor instance 0:
ACC_X[0]: -114, ACC_Y[0]: 37, ACC_Z[0]: 1014

Motion sensor instance 0:
GYR_X[0]: 2170, GYR_Y[0]: -1330, GYR_Z[0]: 2660

Motion sensor instance 0:
ACC_X[0]: -116, ACC_Y[0]: 54, ACC_Z[0]: 1009

Motion sensor instance 0:
GYR_X[0]: 420, GYR_Y[0]: -3150, GYR_Z[0]: 840

Motion sensor instance 0:
ACC_X[0]: -115, ACC_Y[0]: 44, ACC_Z[0]: 1016

Motion sensor instance 0:
GYR_X[0]: 3080, GYR_Y[0]: 840, GYR_Z[0]: 0
```

Fig. 3. Development of the sensor software. (a) Students developing the embedded software; (b) A diagram for inertial measurement unit (IMU); (c) Programming an IMU breakout board by SparkFun™ using a NUCLEO-L476RG microcontroller board by STMicroelectronics™; (d) A screenshot of the IMU outputs on the Tera Term™ serial communication monitor.

Developing on Breakout/Demo Boards



```
[0060] 00 00 00 00 00 00 00 00  . . . . . . . .
[0068] 00 00 00 00 00 00 00 00  . . . . . . . .
[0070] 00 00 00 00 00 00 00 00  . . . . . . . .
[0078] 00 01 00 00 00 00 00 00  . . . . . . . .
[0080] 00 00 00 00 00 00 00 00  . . . . . . . .
[0088] 00 00 00 00 00 00 00 00  . . . . . . . .
[0090] 00 00 00 00 00 00 00 00  . . . . . . . .
[0098] 03 00 00 6D D0 FB 08 00  . . . m . . . .
[00A0] 27 02 E0 50 12 00 00 00  ' . . P . . . .
[00A8] 00 00 00 00 00 00 00 00  . . . . . . . .
[00B0] A7 2E 00 20 08 00 00 00  . . . . . . . .
[00B8] 00 00 00 00 00 00 00 00  . . . . . . . .
[00C0] 00 00 00 00 00 00 00 00  . . . . . . . .
[00C8] 00 00 00 00 00 00 00 00  . . . . . . . .
[00D0] 00 00 00 00 00 00 00 00  . . . . . . . .
[00D8] 00 00 00 00 00 00 00 00  . . . . . . . .
[00E0] 00 00 00 00 00 00 00 00  . . . . . . . .
[00E8] 00 00 00 00 00 00 00 00  . . . . . . . .
[00F0] 00 00 00 00 00 00 00 00  . . . . . . . .
[00F8] 00 00 00 00 00 00 00 00  . . . . . . . .
[0100] 00 00 00 00 00 00 00 00  . . . . . . . .
[0108] 00 00 00 00 00 00 00 00  . . . . . . . .
[0110] 00 00 00 00 00 00 00 00  . . . . . . . .
[0118] 00 00 00 00 00 00 00 00  . . . . . . . .
[0120] 00 00 00 00 00 00 00 00  . . . . . . . .
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[0130] 00 00 00 00 00 00 00 00  . . . . . . . .
[0138] 00 00 00 00 00 00 00 00  . . . . . . . .
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[0150] 00 00 00 00 00 00 00 00  . . . . . . . .
[0158] 00 00 00 00 00 00 00 00  . . . . . . . .
[0160] 00 00 00 00 00 00 00 00  . . . . . . . .
[0168] 00 00 00 00 00 00 00 00  . . . . . . . .
```
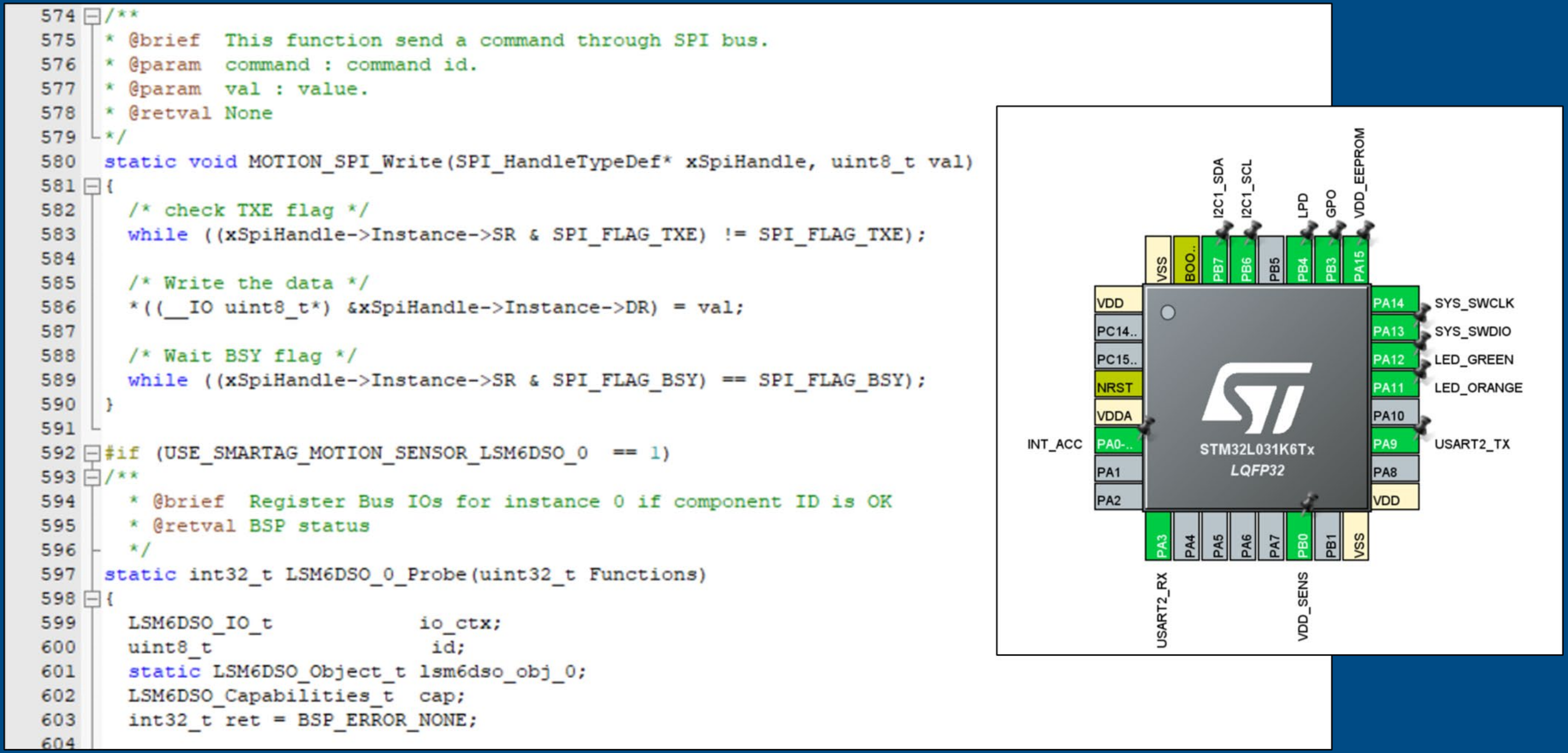

Fig. 4. Development of the NFC software. (a) A sandwiched system consists of X-NUCLEO-IKS01A2 (MEMS expansion board, top), X-NUCLEO-NFC04A1 (NFC tag expansion board, middle), and NUCLEO-L053R8 (MCU board, bottom); (b) STEVAL-SMARTAG-1 NFC tag on X-NUCLEO-NFC06A1 NFC reader; (c) Decoding NFC data exchange format (NDEF) data streamed from the tag to the reader wirelessly; (d) Student programming; (e) Students presenting; (f) Students showcasing.

Development Environment

Several embedded software development environments were used during SPUR 2022, including Keil µVision 5, IAR EW for Arm 9.30.1, and STM32Cube IDE 1.9.0.

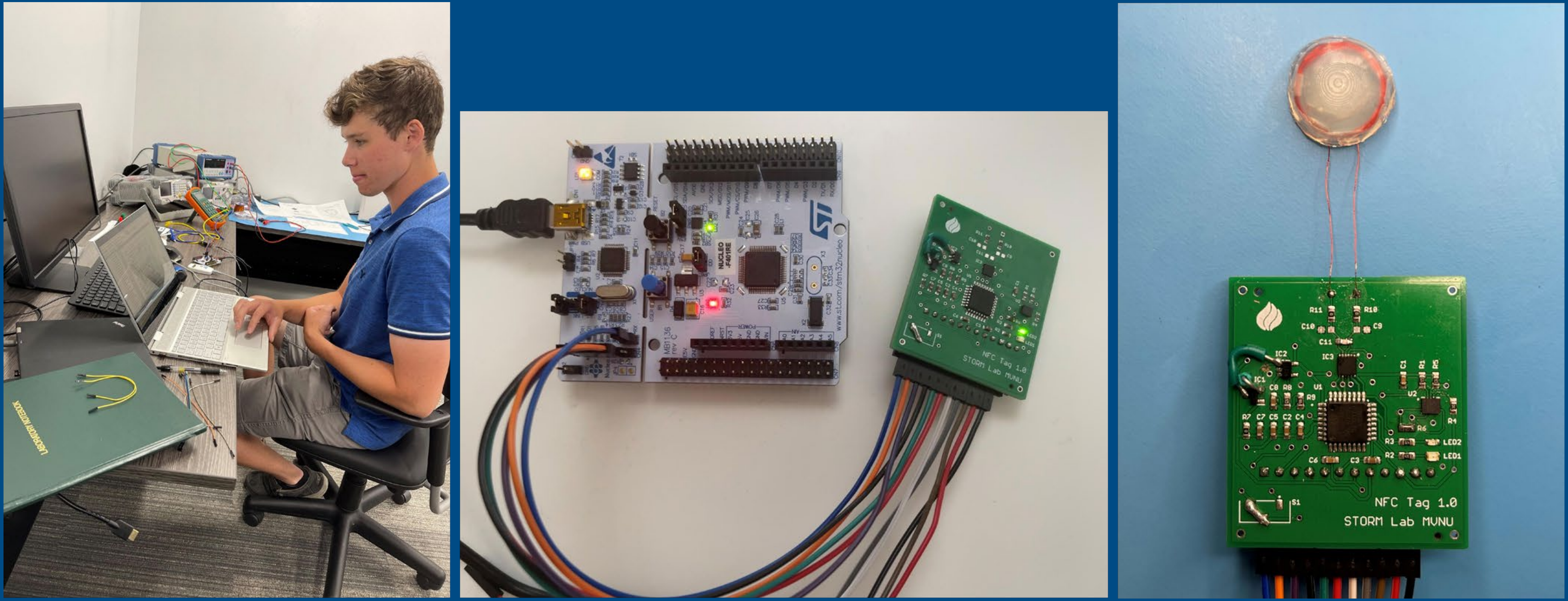


```c
/**
* @brief  This function send a command through SPI bus.
* @param  command : command id.
* @param  val : value.
* @retval None
*/
static void MOTION_SPI_Write(SPI_HandleTypeDef* xSpiHandle, uint8_t val)
{
  /* check TXE flag */
  while ((xSpiHandle->Instance->SR & SPI_FLAG_TXE) != SPI_FLAG_TXE);

  /* Write the data */
  *((__IO uint8_t*) &xSpiHandle->Instance->DR) = val;

  /* Wait BSY flag */
  while ((xSpiHandle->Instance->SR & SPI_FLAG_BSY) == SPI_FLAG_BSY);
}

#if (USE_SMARTAG_MOTION_SENSOR_LSM6DSO_0  == 1)
/**
  * @brief  Register Bus IOs for instance 0 if component ID is OK
  * @retval BSP status
  */
static int32_t LSM6DSO_0_Probe(uint32_t Functions)
{
  LSM6DSO_IO_t            io_ctx;
  uint8_t                  id;
  static LSM6DSO_Object_t lsm6dso_obj_0;
  LSM6DSO_Capabilities_t  cap;
  int32_t ret = BSP_ERROR_NONE;
```

Fig. 5. Embedded software development on STM32Cube IDE. (a) A batch of code that enables SPI communication for the LSM6DSO IMU; (b) Designating the pin functions of the STM32L031K MCU using the pinout GUI of STM32Cube IDE.

Developing on Customized PCB

The embedded software programs developed during the SPUR 2022 were also uploaded to and debugged on the microcontroller on the customized PCB.



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