# SWAYAM NPTEL COURSE ON

## MINE AUTOMATION AND DATA ANALYTICS

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**Module 04:**
**Proximity Sensors and Control System**

**Lecture 08 B:**
**Proximity Sensors and Control System**

# CONCEPTS COVERED

- Proximity Sensors and Control System
- Personnel Proximity Warning System
- Design of the Proximity Warning System (PWS) Based on Bluetooth Beacons and Smart Helmets
- Experiment of the Proximity Warning System Based on Bluetooth Beacon and Smart Helmet
- Results of smart helmet

# Proximity Sensors and Control System

**More and more design engineers are selecting proximity sensors for their versatility, reliability, durability, and cost-efficiency over mechanical switches for access control.**

**Especially when large machinery and heavy vehicles are operating in the mines safety aspect has to be taken care of everything else.**

**Sophisticated proximity alert systems and proximity detection devices are an essential investment to avoid collisions in the mines.**

**Figure 1. Proximity sensor system for human safety**

# Personnel Proximity Warning System (PWS)

- A wearable personnel proximity warning system can prevent collisions between equipment and pedestrians in mines.

- Sensors warn miners by indicating signals and alarm sounds.

- PWS uses a fusion of sensors (Bluetooth beacon & inductive sensors) for detecting proximity and awareness in the mine environment.

- Example: The smart helmet-based PWS can provide visual proximity warning alerts to both the equipment operator and the pedestrian, and it can be expanded to provide worker health monitoring and hazard awareness functions by adding sensors to the Arduino board.

# Design of the Proximity Warning System (PWS) Based on Bluetooth Beacons and Smart Helmets

- A smart helmet-based wearable personnel proximity warning system can be used to prevent collisions between equipment and pedestrians in mines.
- The design of PWS based on Bluetooth beacons and smart helmets is summarized in Figure 2.
- The smart helmet worn by the worker receives a Bluetooth low energy (BLE) signal transmitted from the Bluetooth beacon and provides a visual alert when it comes close to the beacon.

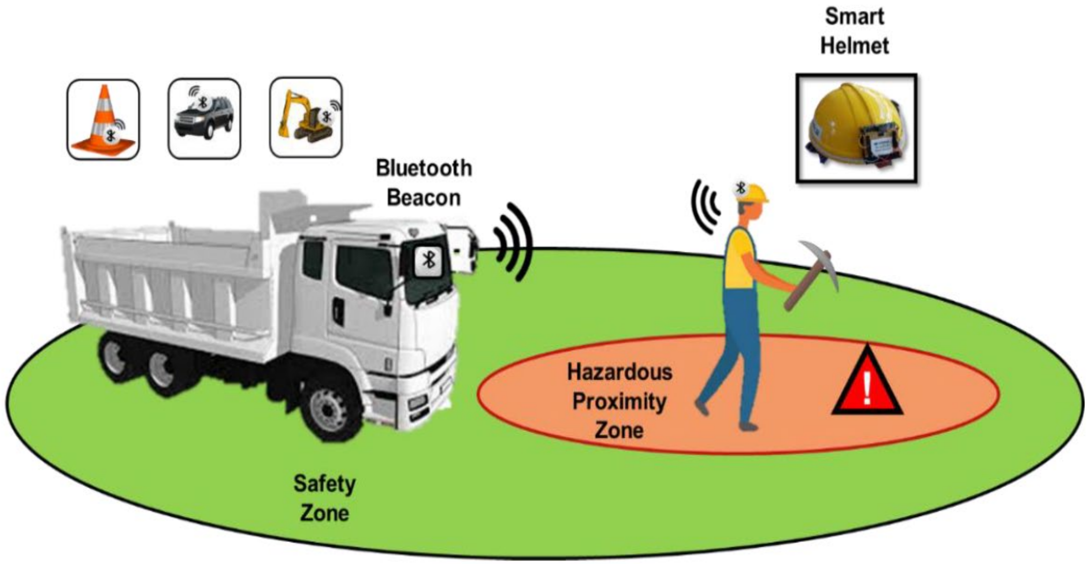



Figure 2. Overview of personal proximity warning system (PWS) using smart helmet.

- The Bluetooth beacon can be attached to heavy equipment, a management vehicle, or a dangerous area at the mine site, and the attached beacon continuously transmits the Bluetooth low energy (BLE) signal.

- The smart helmet can warn wearers of access to heavy equipment or vehicles and access dangerous areas and warn drivers that there are workers nearby.

- Visual proximity alerts are received through a smart helmet while working on the spot; therefore, both workers and drivers can quickly detect and respond to dangerous situations.

- The smart helmet worn by pedestrians receives signals transmitted by Bluetooth beacons attached to heavy equipment, light vehicles, or dangerous zones, and provides visual LED warnings to the pedestrians and operators simultaneously.

# 1. Design of BLE Transmission Units Using Bluetooth Beacon

- **Bluetooth beacons periodically transmit information, including the general-purpose unique identifier of the beacon and media access control (MAC) address through the BLE signal.**

- **The intensity of the BLE signal transmitted by the Bluetooth beacon is expressed as Tx power, and the unit is dBm. dBm is a unit of level used to indicate that a power level is expressed in decibels (dB) with reference to one milliwatt.**

- **The received intensity of the BLE signal can be quantified using the RSSI (Received Signal Strength Indicator) value. RSSI is represented in a negative form by a value between −99 dBm and −35 dBm. Bluetooth RSSI is a measure that represents the relative quality level of a Bluetooth signal received on a device.**

- **The propagation distance of the BLE signal may vary depending on the signal transmission intensity and direction of the signal propagation of the Bluetooth beacon.**

- An increase in the BLE signal transmission intensity increases the signal propagation distance.

- The signal propagation direction is bidirectional, and the signal can be spread uniformly in all directions, but this limits the propagation distance.

- The BLE signal is first propagated relative to the Bluetooth beacon when the signal is transmitted as the directional signal.

- The change in RSSI according to the BLE signal transmission intensity and the direction of the radio wave of the Bluetooth beacon was previously analyzed

In this case study, RECO beacons (Perples, Seoul, Korea) were used as BLE transmission devices.

RECO beacons are certified by institutions in Korea, the United States, Europe, and Japan and meet global beacon standards (Table).

**Table 1. Specifications of the RECO beacon**

| Item | Value |
|---|---|
| Dimensions (Diameter × Height) | 45 mm × 20 mm |
| Weight | 11.6 g (0.4 oz) |
| Processor | 32-bit ARM® Cortex®-M0 |
| Battery | CR2450 Lithium Coin Battery (3 V, 620 mAh) |
| Casing | Acrylonitrile Butadiene Styrene (ABS) Plastic |
| Chipset | Nordic nrf51822 |
| Thermal Resistance | 93 °C (200 °F) |
| Operating Temperature | −10–60 °C (14–140 °F) |
| Wireless Technology | Bluetooth 4.0 (i.e., BLE or Bluetooth® Smart) |
| Signal range | 1 m~70 m (3.2 ft~230 ft) |
| Signal transmission period | Min (10 ms), Max (2 s) |
| Transmission power | Min (−16 dBm), Max (4 dBm) |
| | Korea Certification (KC) |

Figure 3 shows examples of heavy equipment and vehicles at the mine site with RECO beacons.

A Bluetooth beacon was installed on the back of the room mirror on the front of the truck, and a Bluetooth beacon was provided on the front of the heavy equipment.

The Bluetooth beacons set the directional signal such that the signal could be propagated further. The signal transmission strength and period of the beacons were set to - 4 dBm and 1 s, respectively.


Bluetooth beacons periodically transmit information, including the general-purpose unique identifier of the beacon and media access control (MAC) address through the BLE signal.

Figure 3. Bluetooth beacons attached to trucks (a,b) and excavators (c, d).

# 2. Design of BLE Receiver Units Using an Arduino Board

**Arduino is an open source electronic platform based on easy-to-use hardware and software (Table 2).**

**The Arduino board reads the input data, including sensor illumination and button pressing and converts it into output data.**

**Because the Arduino board and software are open sources, users can independently build boards to adjust the system to meet specific needs.**

**Table 2. Specifications of the Arduino Uno board**

| Item | Value |
|---|---|
| Model | Arduino Uno R3 |
| Microcontroller | ATmega328P |
| Length | 68.6 mm |
| Width | 53.4 mm |
| Weight | 25 g |
| Operating Voltage | 5 V |
| Input Voltage | 7–12 V (recommended), 6–20 V (limit) |
| Digital I/O Pins | 14 (of which 6 provide PWM output) |
| PWM Digital I/O Pins | 6 |
| Analog Input Pins | 6 |
| DC Current per I/O Pin | 20 mA |
| DC Current for 3.3V Pin | 50 mA |
| Flash Memory | 32 KB (ATmega328P) of which 0.5 KB used by bootloader |
| SRAM | 2 KB (ATmega328P) |
| EEPROM | 1 KB (ATmega328P) |
| Clock Speed | 16 MHz |
| LED_BUILTIN | 13 |

The circuit diagram was used to visualize the connection method of the Arduino board, LED, and Bluetooth module as shown in Figure 4.

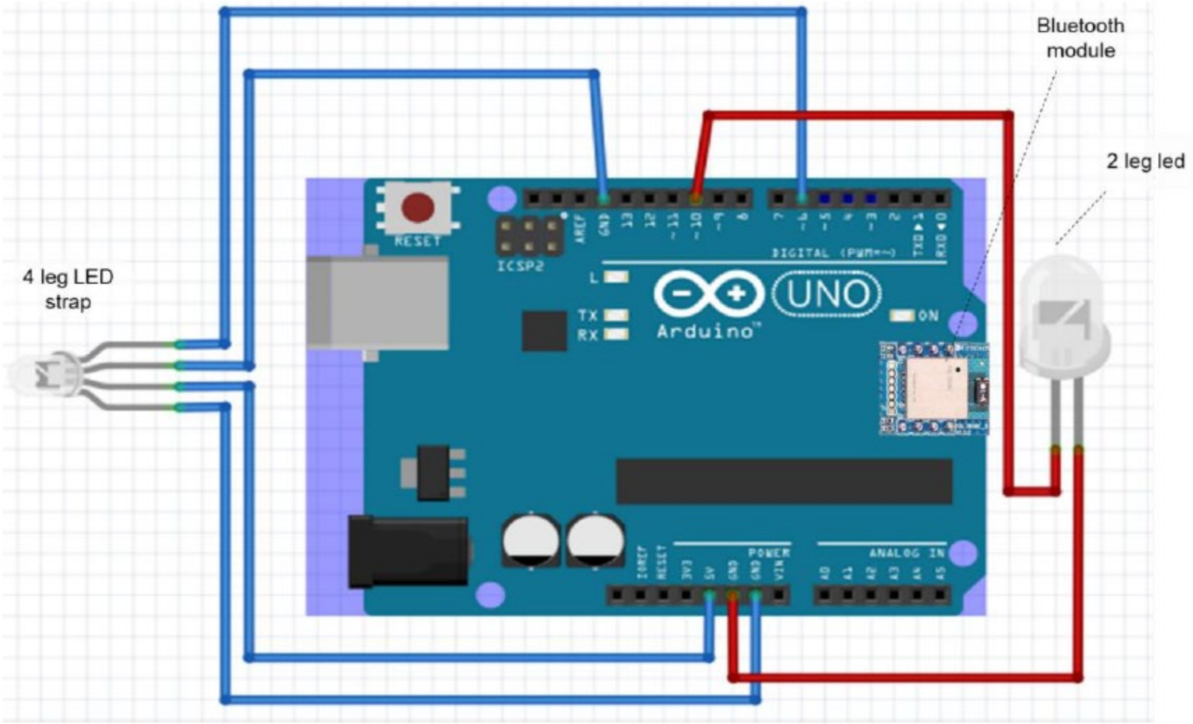



Figure 4. Circuit diagram of Arduino application.

In this study, a smart helmet was developed to develop a wearable personal PWS for mine workers.

The smart helmet was made by combining an Arduino Uno board, Bluetooth BLE module (FBL780BC, Table 3), LED strap, and two-leg LEDs with the safety helmet worn by mining workers.

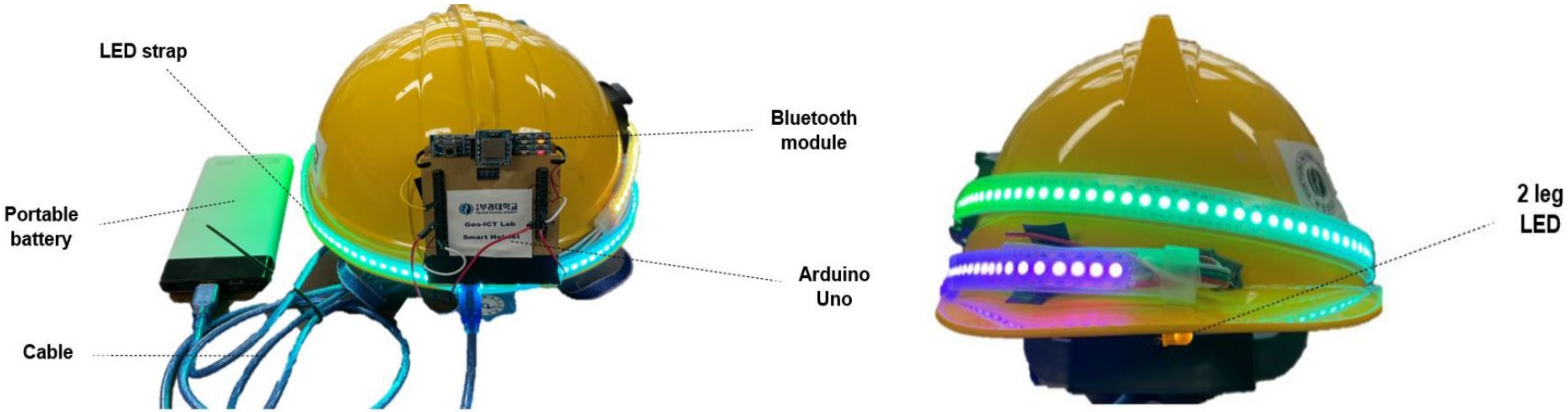
**Table 3. Specifications of Bluetooth module**

| Item | Value |
|---|---|
| Model | FBL780BC |
| Bluetooth specification | Bluetooth4.1Low Energy Support |
| Communication distance | 10 m |
| Frequency range | 2402~2480 MHz ISM Band |
| Sensitivity | −94 dBm |
| Transmit power | 2 dBm (−3 dBm: Actual value after matching) |
| Size | 15.5 mm × 18.5 mm |
| Input power | 3.3 V |
| Current consumption | Peripheral: 3 mA (Max), Central: 21 mA (Max: Scanning) |
| Operating temperature | Min: −10 °C, Max: 50 °C |
| Communication speed | 2400 bps~230,400 bps |
| Antenna | Chip Antenna |
| Interface | UART |

**Figure 5a,b show the exterior shape of the equipment divided into front and rear parts.**

**The smart helmet provides visual warnings through LED straps (using two-leg LEDs), and receiving power through portable batteries.**

**The Bluetooth BLE module (FBL780BC) supports Bluetooth Low Energy, a low-power function based on Bluetooth 4.1.**




(a) (b)

**Figure 5. The component of the smart helmet. The rear part (a) and the front part (b) of the helmet**

**The process of the operating algorithm of the smart-helmet PWS is illustrated in Figure 6.**

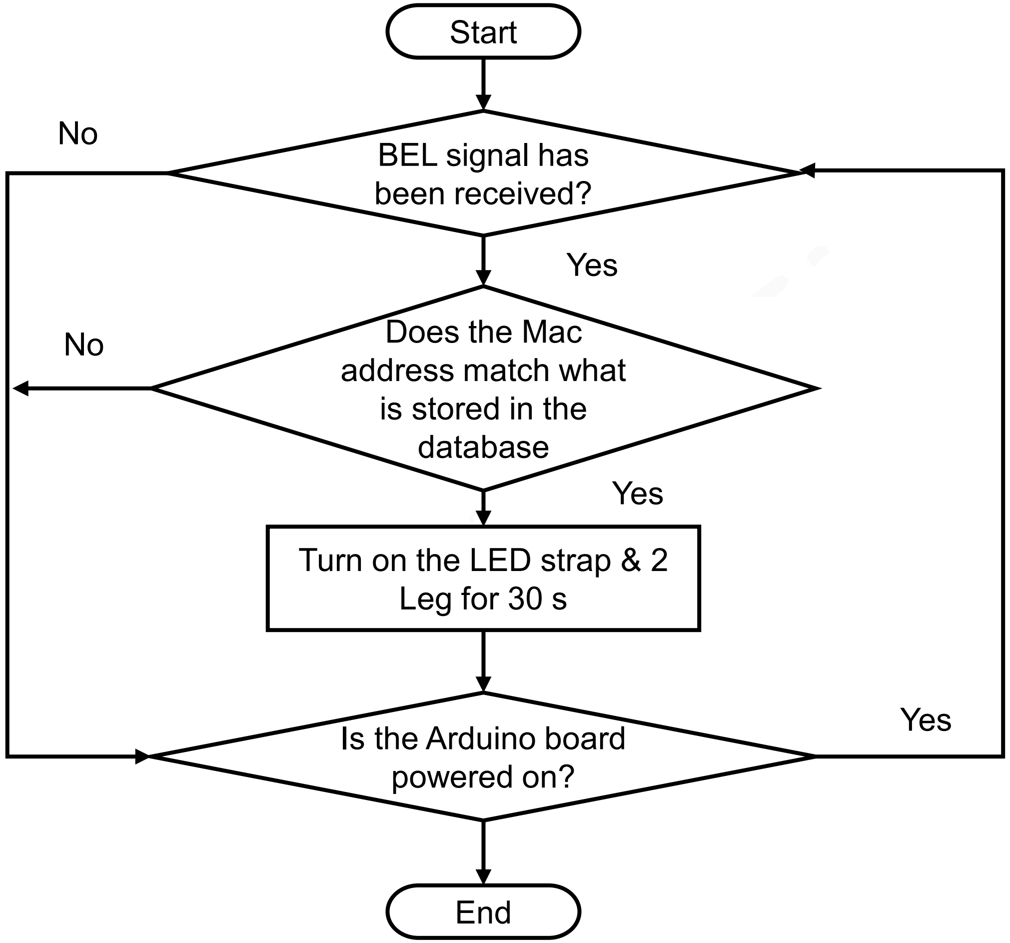



**Figure 6. The process of the operating algorithm for the smart helmet-based personal proximity warning system.**

# Experiment of the Proximity Warning System Based on Bluetooth Beacon and Smart Helmet

## A. Performance Evaluation of Personal PWS Based on Smart Helmets

**To evaluate the performance of the developed smart helmet-based personal PWS, a field experiment was conducted at the Sungshin Minefield underground limestone mine located in Jeongseon-gun, Gangwon-do, Korea.**

**Figure 7 shows the tunnels that have been tested in the field on a two-dimensional and three-dimensional map and an actual photograph.**

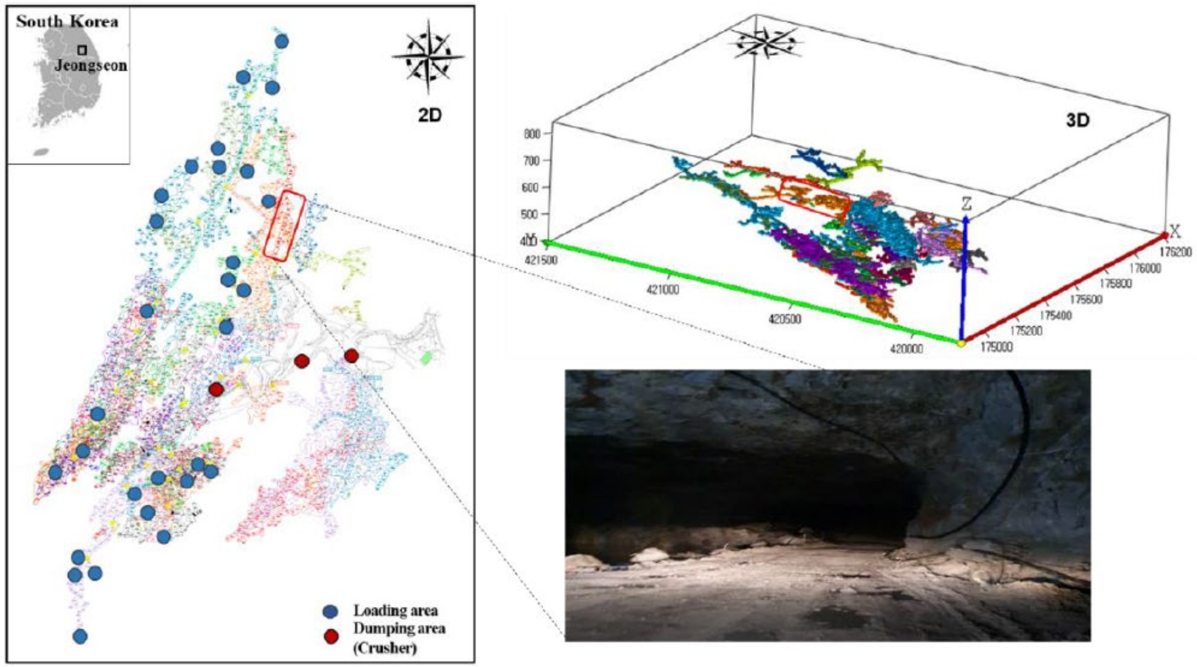



**Figure 7. Underground map of the study area (Sungshin Minefield underground limestone mine, Jeongsun-gun, Gangwondo, Korea) in 2- and 3-dimensions, and an actual photograph.**

Figure 8 shows the smart helmet measuring the detection distance of receiving the BLE signal for each Tx power.

The Bluetooth module that receives the BLE signal was installed at the rear of the helmet, and the Bluetooth module and Bluetooth beacon attached to the vehicle were arranged to face each other.

The Bluetooth beacon, attached to the truck, approached a pedestrian standing on a mine way transport route 100 m away at a speed of 10–20 km/h.

We then measured the detection distance at which the personal PWS receiving the BLE signal began warning pedestrians. The Tx power was set at 4 dBm intervals from — 12 dBm to 4 dBm and measured 10 times for each Tx rower (50 times total)

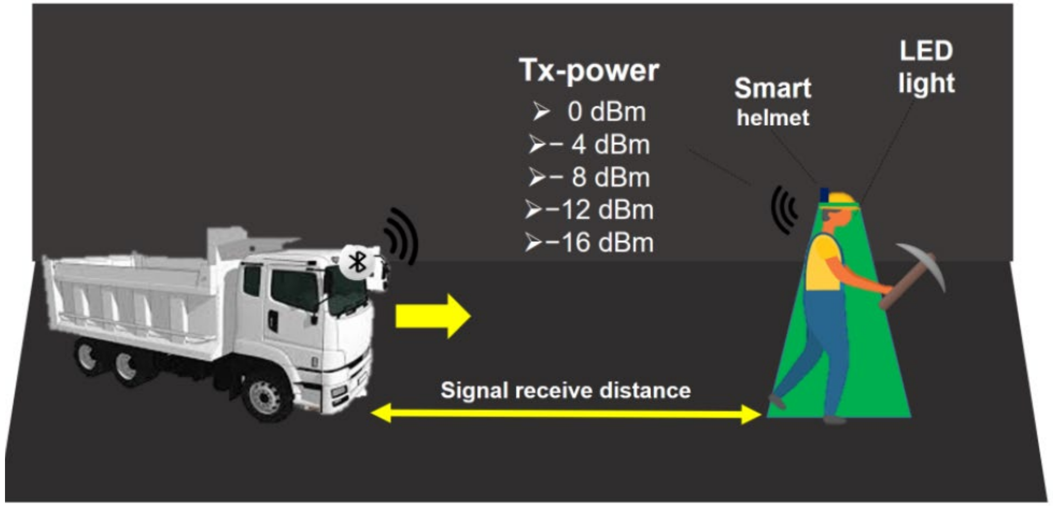



Figure 8. Experimental model of BLE signal detection distance measurement performed by considering the Tx power of the Bluetooth beacon.

Figure 9 shows an experiment that measures the detection distance of a smart helmet receiving a BLE signal via adjusting the angle between the Bluetooth beacon and the smart helmet.

Similar to the above experiment, the truck approached at speeds of 10–20 km/h, and the detection distance at which the warning commenced was measured.

The angles between the smart helmets and beacons were set at 45 intervals—from 0 to 180, and measured 10 times for each angle (50 measurements in total).

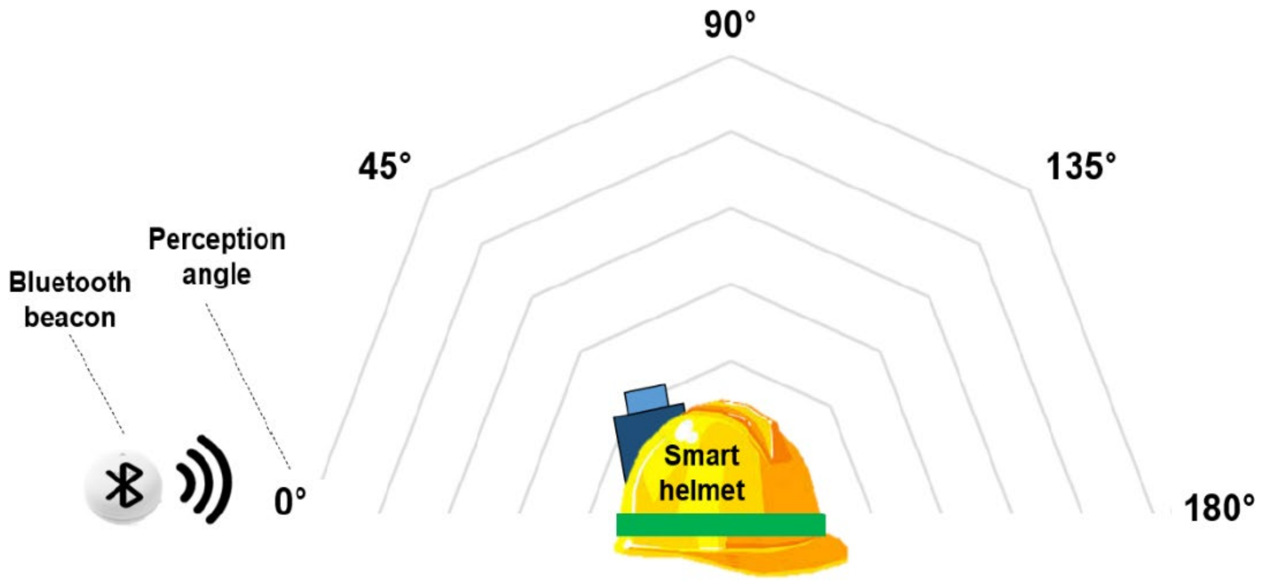



Figure 9. BLE Signal detection distance measurement model according to the perception angle between the Bluetooth beacon and the smart helmet.

## B. Subjective Workload Assessment of Smart Helmet-Based Personal PWS

**Three equivalent experiments were performed under the same experimental conditions to compare the effect on the subjective workload.**

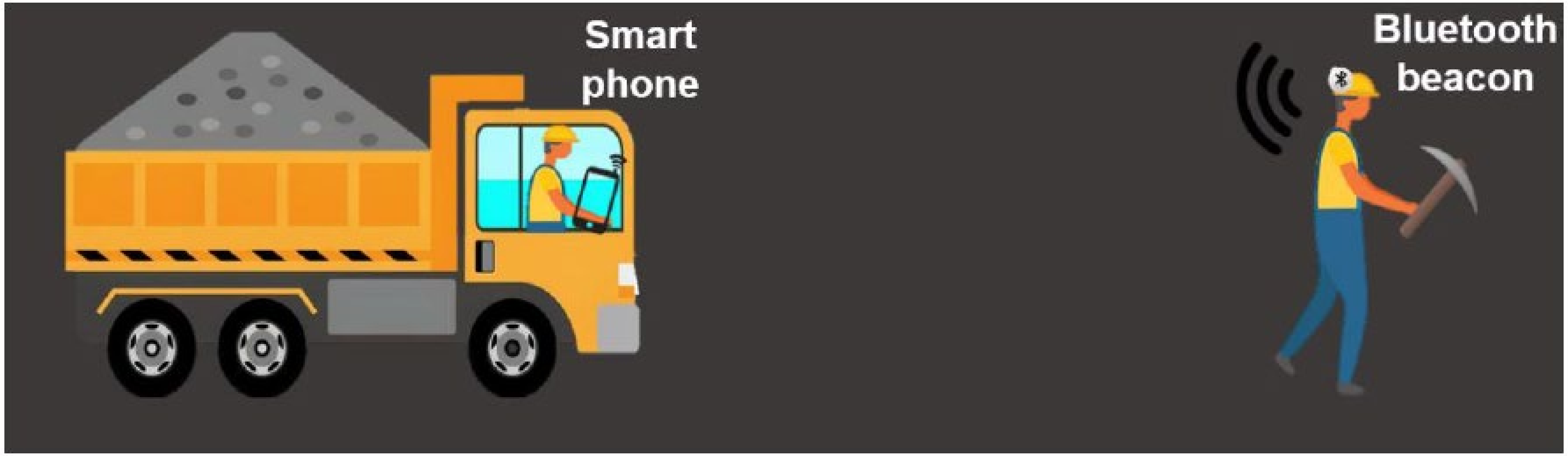
**In this study, the subjective workload evaluation was performed on 10 experimental subjects aged 24 to 26 years old (average age was 24.9 years) at the same location where individual PWS performance was evaluated.**

**More than half (60%) of the test subjects said they had knowledge of smart glasses, and the majority (80%) said they had no knowledge of smart helmets.**

**The test subjects used (a) a smartphone-based personal PWS (driver's position), (b) a smart glass-based personal PWS (worker's position), and (c) a smart helmet-based personal PWS (worker and driver's position).**

In the experiments, the test subject stood at the center of the transport route and examined the condition of the transport route (worker's position) or boarded a truck or loader (driver's position) to approach the subject.

The smartphone provided a proximity warning to the driver with a hazard warning image.




(a)

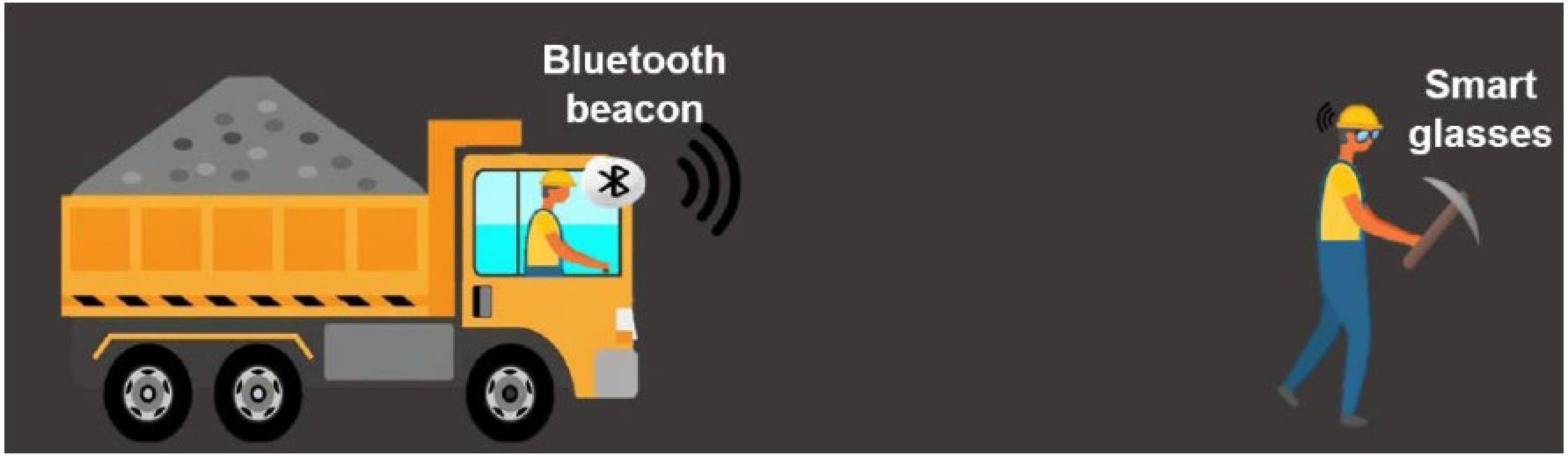
Figure 10. (a) Type 1: truck drivers wearing the smartphone-based PWS.

Smart glass provides a proximity alert to a worker with a hazard warning image.

The smart helmet turned on the LED to provide a visual warning to both the driver and worker.

In one case, the test subject boarded a loader or truck (driver’s position) and when the device sensed that the worker was nearby, the vehicle was stopped temporarily.

The worker passed only after confirming the evacuation.




(b)

Figure 10. (b) type 2: pedestrian workers wearing the smart glasses-based PWS.

In another case, the test subject examined the transport route's maintenance status (worker's position), and the operation was stopped when the device sensed that a vehicle was approaching.

The subject evacuated to the side of the transport route, and only after the vehicle had passed did the operation resume.


(c)

Figure 10. (c) type 3: truck drivers and pedestrian workers wearing the smart helmet-based PWS.

(a) (b)

**Figure 11. Experimental results showing the performance of the smart-helmet based PWS. (a) Worker wearing the smart helmet when no BLE signal is received; (b) worker wearing the smart helmet when a BLE signal is received.**

# Results of smart helmet

- Figure 11a shows the worker wearing a smart helmet when a BLE signal is not received, and Figure 11b shows the worker wearing a smart helmet when a BLE signal is received.

- The MAC address of the Bluetooth beacons to be attached to the mining equipment was stored in a personal PWS application program, and the smart helmet PWS was designed to provide visual alerts through LEDs when the BLE signals were received.

- Through the visual alarm, through LEDs, both the worker and driver can recognize the danger in advance and prevent accidents

Figure 12 shows the average detection distance per Tx power as a graph.

The average detection distance is 2.9 m at -12 dBm, 6.0 m at -8 dBm, 27.1 m at -4 dBm, 62.7 m at 0 dBm, and 66.9m at 4 dBm.

As the Tx power increased, the smart helmet's BLE signal detection distance also increased.

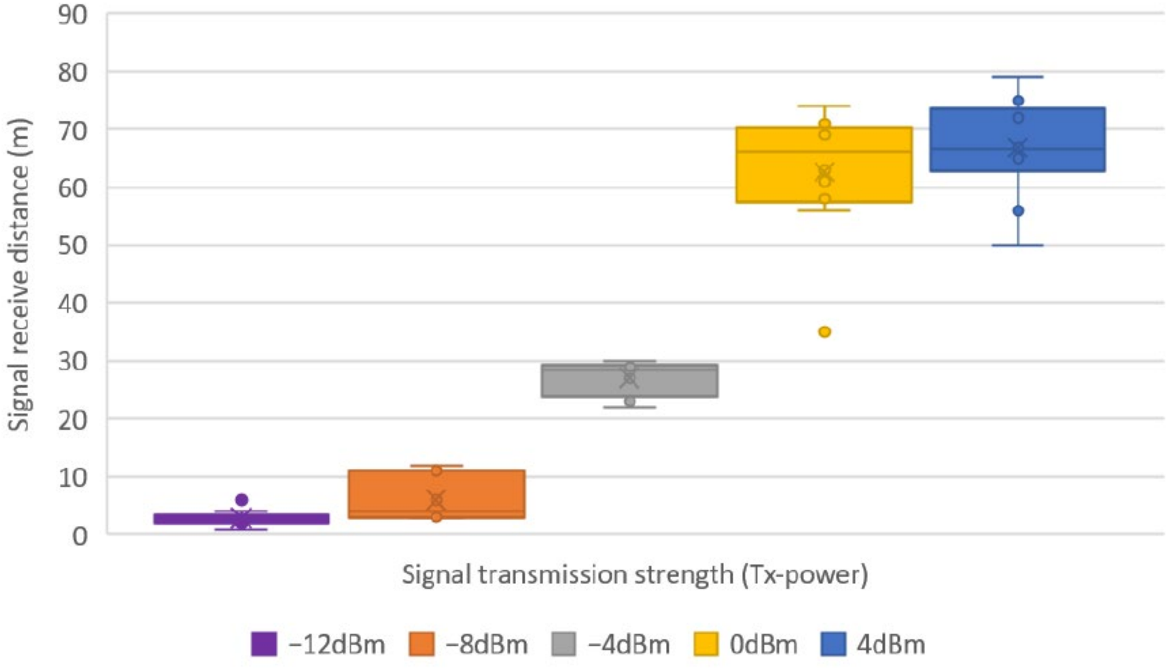



Figure 12. Average BLE signal detection distance of smart helmet according to Tx power of Bluetooth beacon (m).

# BLE Signal Propagation in Underground Mines

- **Structural Challenges: 90-degree inclined crossings and curved sections impede line-of-sight.**

- **Environmental Factors: Rough mine walls cause signal diffraction and reflection. Rock mass leads to radio signal attenuation. High humidity and suspended dust affect air quality.**

- **Electromagnetic Interference: Power supply installations create electromagnetic fields. Potential interference with BLE signals.**

- **Testing Objectives: Assess signal stability in complex mine environments. Understand diffraction, reflection, and interference effects.**

- **Testing Importance: Enhance communication reliability in mines. Inform design for robust BLE systems. Improve safety and efficiency.**

# Advantages of Smart Helmet-Based PWS

- **Enhanced Alert System: Solves issues of distraction by eliminating the need to check smartphones for warnings. Visual proximity alerts on smart helmets ensure quick identification of danger without disrupting work.**

- **Comfort and Compatibility: Overcomes discomfort caused by smart glasses for workers wearing regular glasses or experiencing slippage. Workers with regular glasses, industrial goggles, and soundproof headsets can use smart helmets comfortably.**

- **Ease of Use: Simplifies operation compared to existing PWSs requiring touchpad controllers. NASA-TLX test indicates users find the smart helmet-based PWS more convenient.**

- **Cost-Effective Implementation: Utilizes Arduino, an open-source hardware, reducing system costs. Allows for the distribution of multiple smart helmets and Bluetooth beacons, making it adaptable to mines of various sizes.**

- **Quick Evacuation Capability: Facilitates rapid evacuation by providing visual proximity alerts without work interruption. Enhances safety by ensuring quick response to dangerous situations.**

- **Broad Applicability: Suitable for diverse workers, including those wearing regular glasses and industrial goggles. Can be implemented across mines of varying sizes due to its cost-effective design.**

# REFERENCES


- Kim, Y.; Baek, J.; Choi, Y. Smart Helmet-Based Personnel Proximity Warning System for Improving Underground Mine Safety. Appl. Sci. 2021, 11, 4342. https://doi.org/10.3390/app11104342
- RECO Beacon. Available online: http://reco2.me/
- Bluetooth Module Specification. Available online: http://www.firmtech.co.kr/default/product/bluetooth/fbl780bc.php#01

# CONCLUSION

- A proximity sensor is a device that detects the presence or absence of an object or a person within a certain range without any physical contact.
- We have discussed with an example the utility of proximity sensing system to enhance workers safety in the mines using smart helmets.
- The results are optimistic and shows that, it can be customized and mines specific needs may be served well.


THANK YOU