Mine Automation and Data Analytics

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Week-4

Lecture-16

Proximity Sensors and Control System

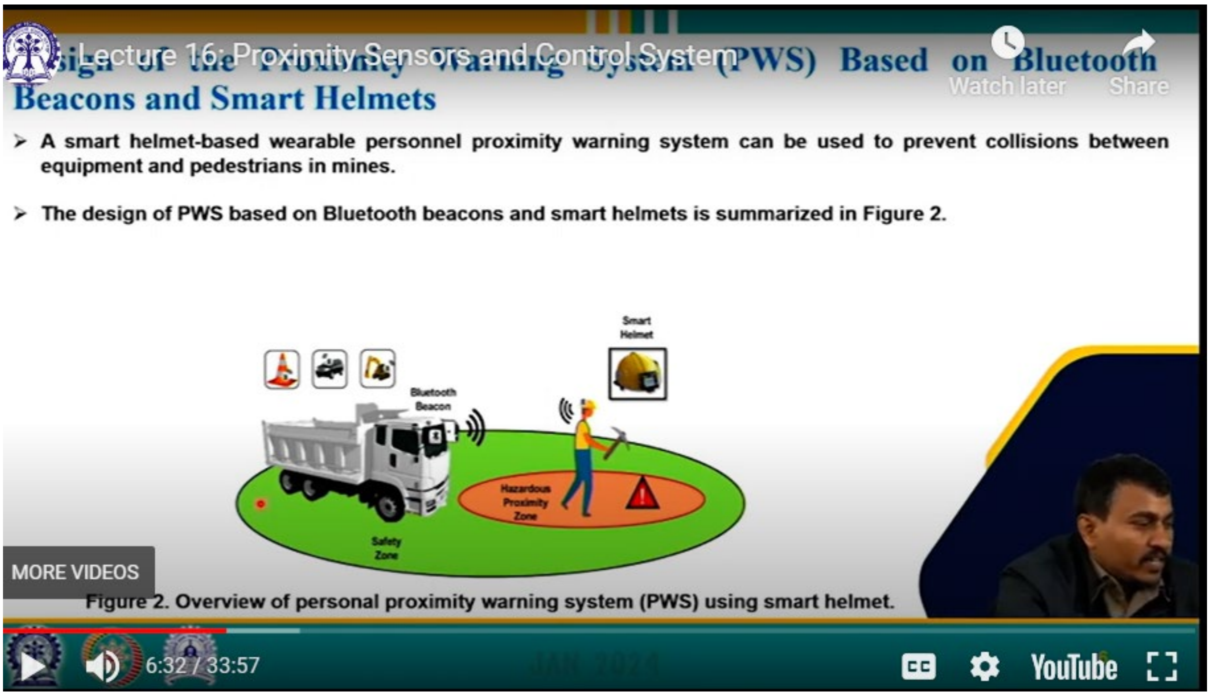
Welcome back to my course, Mine Automation and Data Analytics. Today, we are going to discuss on Proximity Sensor and Control System that is used in Mine Automation Systems. So, in this lecture, we are going to cover the following. Proximity sensors and control system, personal proximity warning system, 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 and we will finally discuss the result of this experiment. Proximity sensors and control system. So, nowadays the engineers are choosing and selecting the proximity sensors for their versatility, reliability, durability and its cost efficiency over other available mechanical switches for access control.

So, this is a very cost effective and handy sensing system for applying some cases where automatic control is necessary. So, especially when large machineries are operating in a mines, side by sides also workers are working in the mine site. So, safety of the workers as well as safety of the vehicles are utmost important. So, in these cases, proximity sensing system can provide a solution, a safe solution for smart operation of all these machines.

So, here a sophisticated proximity alert system and proximity detection devices are an essential investment to avoid collisions in the mine. So, typically if you look into this particular figure, here it is been shown that a heavy earth moving machinery is operating in a mine and you can see the in the distance there is one worker is also working. So, there might be the chances that that particular machine hit this worker or the worker unconsciously came into the track of this particular machine. So, to avoid that kind of consequences, there is a necessity of development of a control system that will ensure the safety of the worker as well as the safety of the shift where these machines will safely operate as well as the miners that is they are working in the mine site, they can also work simultaneously, safely without any chances of any accident or collision. So, keeping in view of that, the case study that we are going to discuss today, they have developed a personal proximity warning system.

So, it is a wearable solution. So, using the helmets and using the smart devices, this particular case study has provide an unique solution. So, this wearable personal proximity warning system can prevent collision between the equipment and pedestrian in the mines. So, the sensor warns miner by indicating signals and alarm sounds and this PWS uses a fusion of sensors, Bluetooth beacons, inductive sensors for detecting proximity and awareness in the mine environment. So, the example here we have used is a smart helmet-based proximity warning system PWS that provides visual proximity warning alerts to both the equipment operator and the miners working in the vicinity.

So, it can be expanded to provide workers health monitoring and hazard awareness function as well by adding sensors to the Arduino board. So, let us discuss on the design aspect of the proximity warning system based on Bluetooth beacons and smart helmets. A smart helmet based wearable personal proximity warning system can be used to prevent collision between the equipment and the miners working in the mines. So, the design of the PWS is illustrated here in this figure. So, if you see the figure, here is the vehicles are operating on this particular zone.



So, for the vehicle if other warning is not there, the vehicle is operating on a safe zone. Now, in front of it another miners worker is working in that particular mine site for some task. So, his or her area is also safe to that extent, but it will be not safe when this particular machine is coming close to this particular area. So, when the machine is coming close to this particular area, then this particular zone will become hazardous because here miners are working. Miners might not be aware that the vehicle is came closer to him or her.

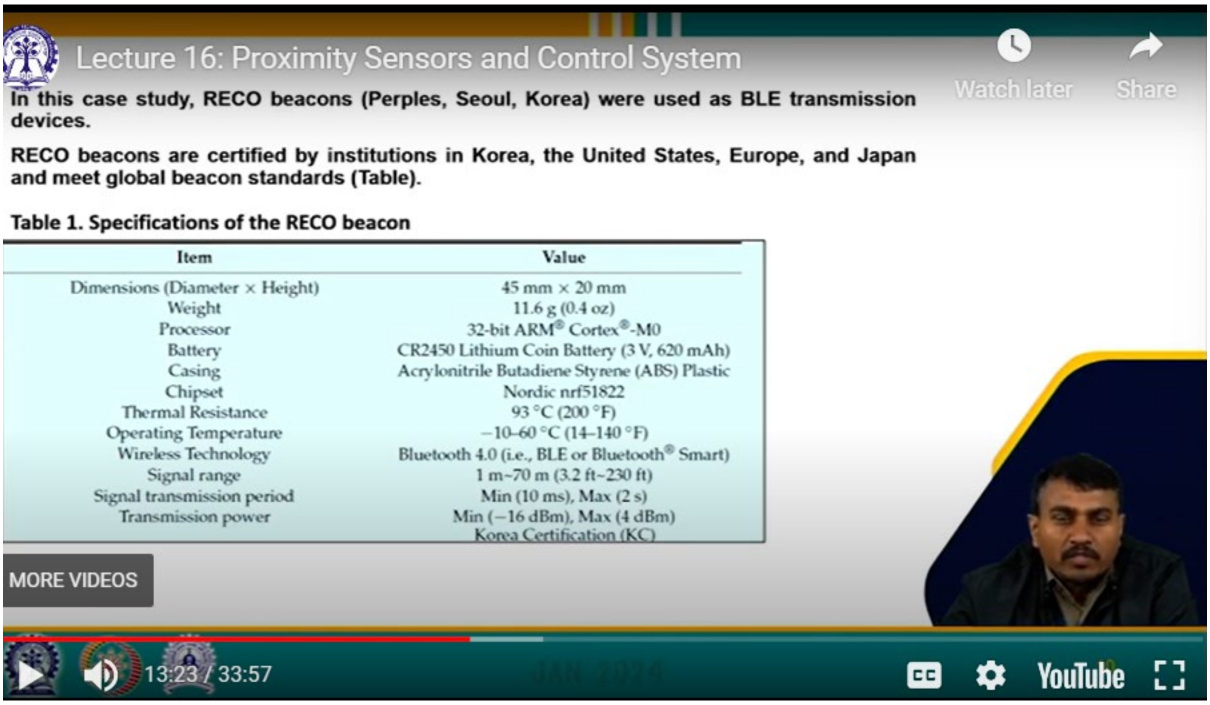
So, there is a necessity to define this particular zone as a hazardous with a hazardous proximity zone that some kind of beacon sounds or alert may be activated whenever the vehicle will come closer to this area. So, that the operator will be intimated as well as the worker who is working in this particular area, he or she will also be alerted that something or some vehicle came closer to him or her. So, that basically the proposal of developing the proximity warning system using the smart helmet and that wearable things will be added in the helmets. The devices, the sensors will be added on the helmets. So, that workers does not need to carry any extra material for this kind of system.

So, the smart helmet owned by the workers receive a Bluetooth low energy signal transmitted from the Bluetooth beacon and provides a visual alert when it comes close to the beacon. The Bluetooth beacon can be attached to heavy equipment or the light vehicle that is operates on the mine site and that will be also attached with a beacon that will continuously transmit the Bluetooth low energy signal. The smart helmet can warn wearers of the access to heavy equipments or vehicle and access dangerous areas and warn the driver that there are workers nearby. Visual proximity alerts are received through a smart helmet while working on the spot. So, therefore both worker and driver can quickly detect and respond to dangerous situations.

The smart helmet owned by the miners receive signal transmitted by Bluetooth beacons attached to heavy equipment or light equipment in the dangerous zone and provide visual LED warning to the miners and operators simultaneously. So, let us discuss the design of the Bluetooth system and its transmission system in the Bluetooth beacon. The Bluetooth beacon periodically transmits information including the general-purpose unique identifier of the beacon and the media access control MSC 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 and this dBm is a unit of level used to indicate that a power level is expressed in decibel with a reference to one milliwatt. The received intensity of the BLE signal can be quantified using the RSSI value that is received signal strength indicator.

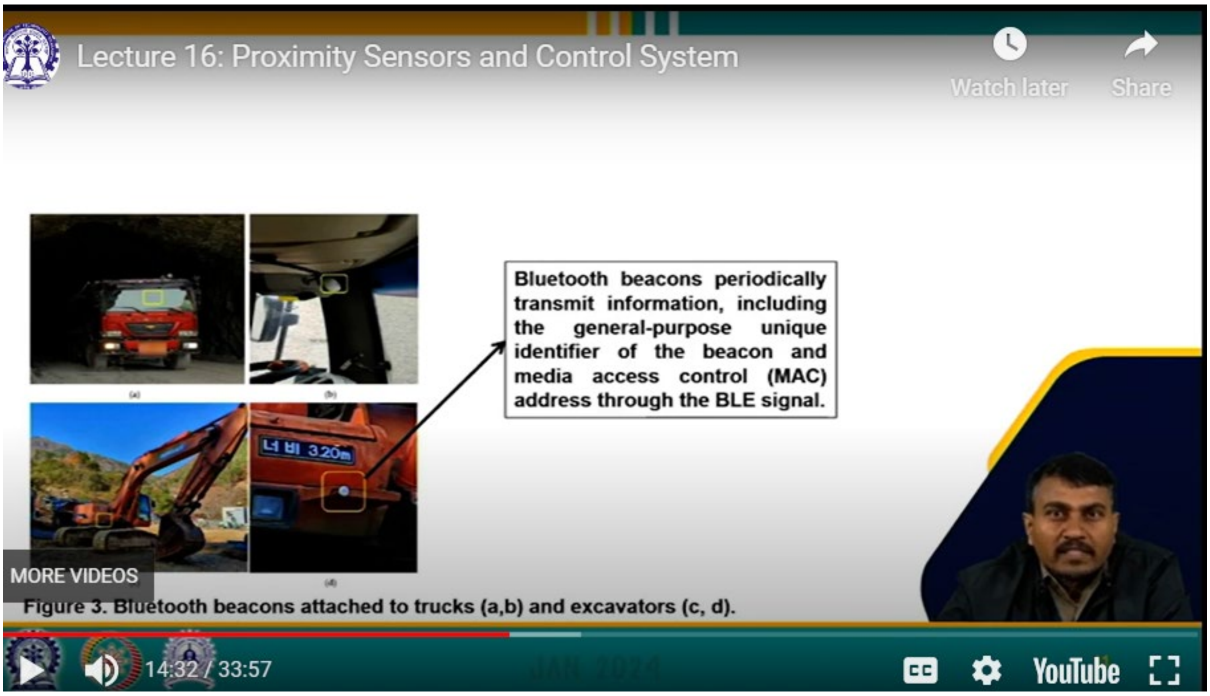
So, this RSSI is represented in a negative form by a value between - 99 dBm and - 35 dBm and Bluetooth RSSI is a measure that represent the relative quality level of a Bluetooth signal received on a device. So, this RSSI value is a logarithmic and it is negative and the unit is expressed in dBm. The 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 will increase the signal propagation distance. The signal propagation direction is bidirectional and the signal can be sprayed uniformly in all direction, but this limits the propagation distance.

The BLE signal is first propagated relative to the Bluetooth beacon when the signal is transmitted as the bidirectional 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. So, in this case study, Reco Beacons purpose Seoul, South Korea were used as BLE transmission devices. So, Reco becons are certified by the institution in Korea, the United States, Europe, Japan and meet global beacon standards. So, this is the typical specification of the Reco Becons.



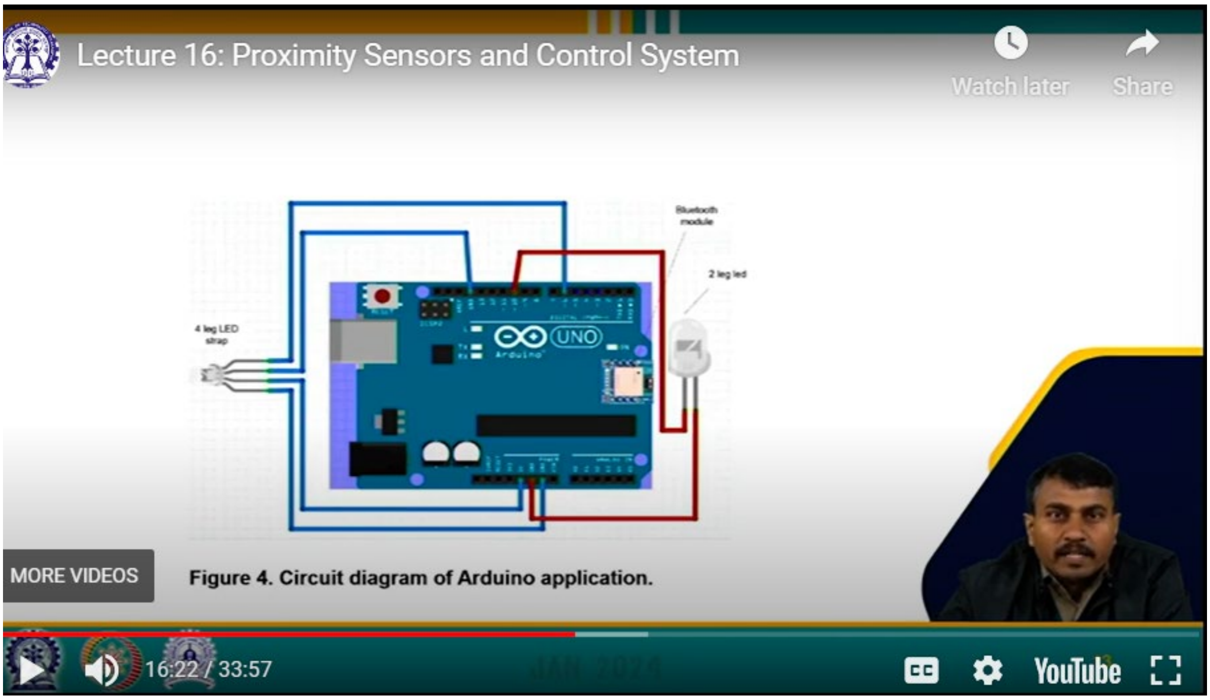
Here this Reco Becons use the 32-bit ARM cortex M0 processor. So, this is a very efficient and very energy efficient processor, use very low power. Side by side is also use the chip set of Nordic NRA 5182822 or chip set that is also very an ultra-low energy chip on the system on chip and that is basically use the 2.4 wireless transmitter proprietary transmission wireless technology and the distance that it covers from 1 meter to 70 meters. So, this is a typical image of the Bluetooth beacons attached to the trucks and excavators at their machines front and the back.

So, the Bluetooth beacons periodically transmit information including the general purpose unique identifier of the beacon and media access control MSC address through the BLE signal. So, a Bluetooth beacon is installed on the back of the room mirror on the front of the truck and a Bluetooth beacon provided on the front of the heavy equipment. The Bluetooth beacon set the directional signal such that signal can be propagated further, the signal transmission strength and periods of the beacon were set to minus 4 dBm and 1 second respectively. Design of BLE receiver units using an Arduino board. So, this is the specification of the Arduino board.



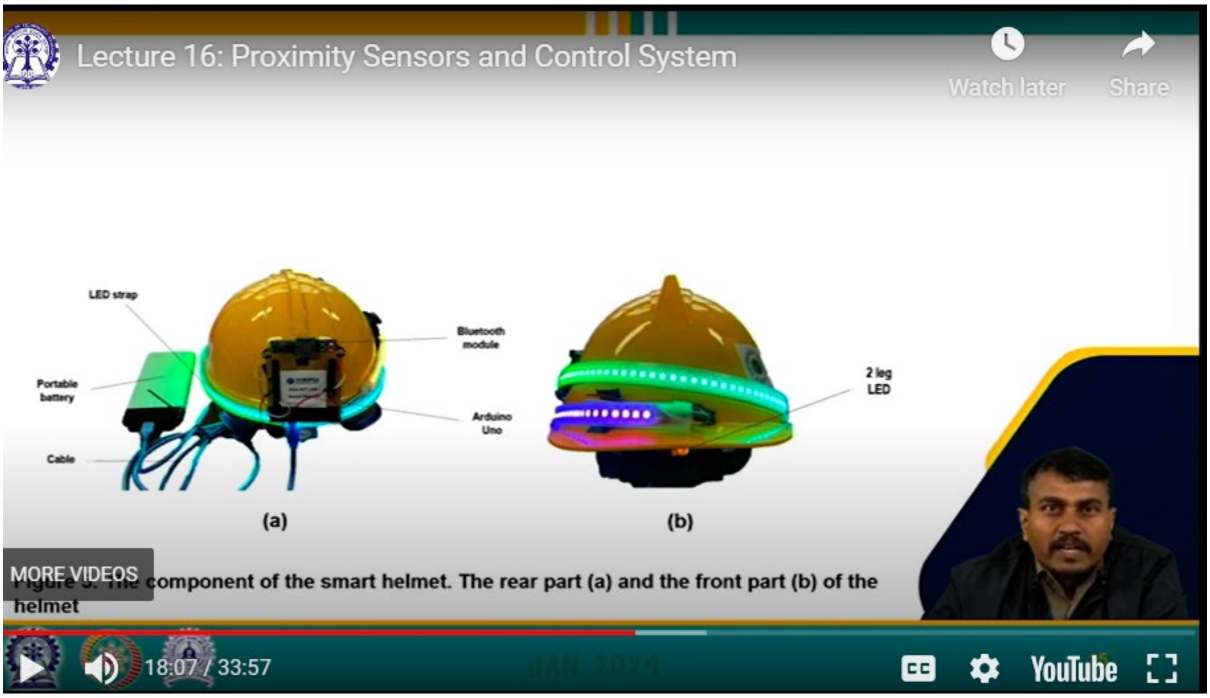
So, these Arduino use the AT mega328P microcontroller. It is basically AT mega basically the manufacturer initially they develop this microcontroller. This microcontroller is a very smart microcontroller and very energy efficient microcontroller and this particular micro-Arduino UNO board have several pins attached to it. Arduino is an open-source electronic platform based on easy to use hardware and softwares. The Arduino board reads the input data including the sensor illumination and button pressing and convert it into output data.

Because the Arduino board and the software are open-source user can independently build boards to adjust the system to meet specific needs. So, this is the typical structure of the circuit diagram of the Arduino application. So, on the left side you can see the four leg LED strap for the connection as well as here the two leg LED strap and here also the Bluetooth module is installed at the at the circuit. So, in this study a smart helmet was developed to develop a wearable personal proximity warning system for mineworkers. The smart helmet was made by combining an Arduino UNO board as we have seen already.

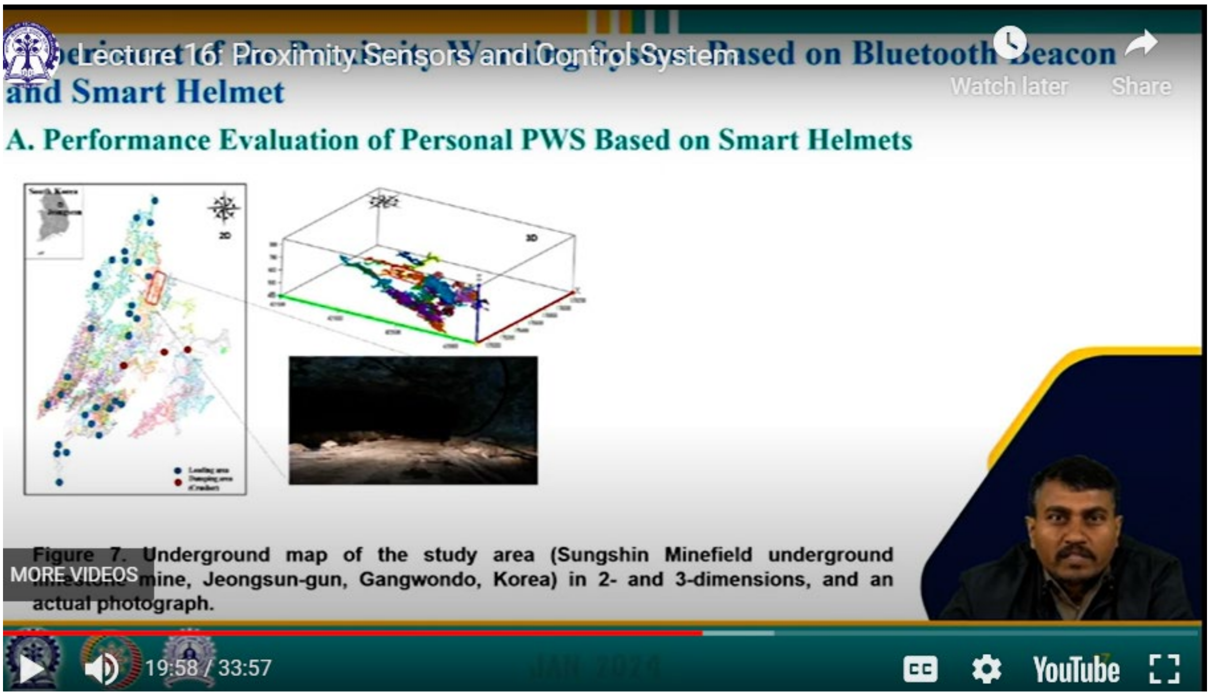


Bluetooth BLE module that also been discussed LED strap two leg LED with the safety helmet owned by the mining workers. So, this is basically the specification of the Bluetooth module. It is basically use the UART interface that is basically universal asynchronous receiver and transmitter. This particular interface does not communicate with the digital clock rather it basically transmit the data asynchronously. So, that is this is also very energy efficient module and all these modules are designed, so that low power is required to maintain this system.

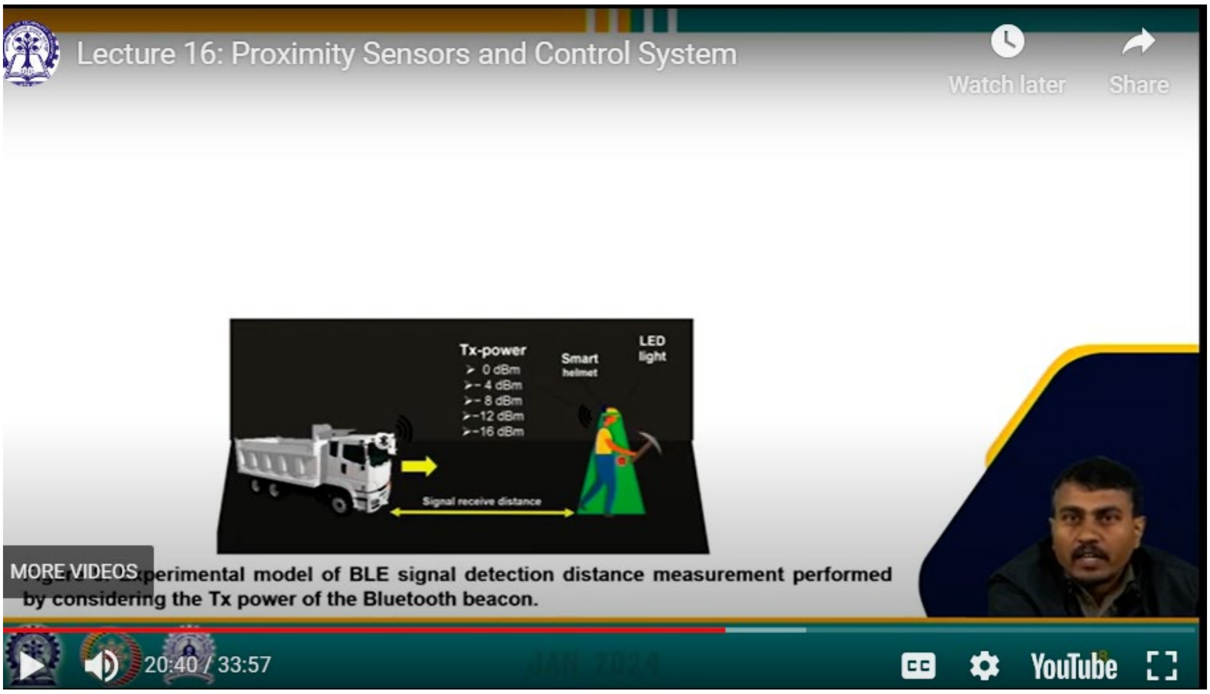
So, this is a typical picture of the component of the smart helmet the rear part and the front part with the portable batteries and the LED strap and the cables. So, as the user as the miner those who will wear it, so they do not have to carry much accessories for these devices the smart helmets and all are lightweight. So, the smart helmet provide visual learning through LED strap using two leg LED and receiving power through the portable batteries. And the Bluetooth BLE module supports Bluetooth low energy a low power function based on Bluetooth 4.1.



So, this is the typical process that operates the algorithm of the smart helmets with personal proximity warning system. So, initially it will start and whether the BL signal has been received if it is yes, does the MAC address match what is stored in the device if it is yes, turn the LED strap and two leg for 30 seconds. So, the warning is alerted the light is on is the Arduino board power on and if it is yes then again goes the that like that it is continually goes on. So, here using this system there was an experiment conducted with the user and the vehicle operators to test the efficiency of this system. So, this figure 7 describe the underground maps of the study area, Sengshin minefield underground limestone mine in Jeongshan-gong, Guangdong in Korea, South Korea.



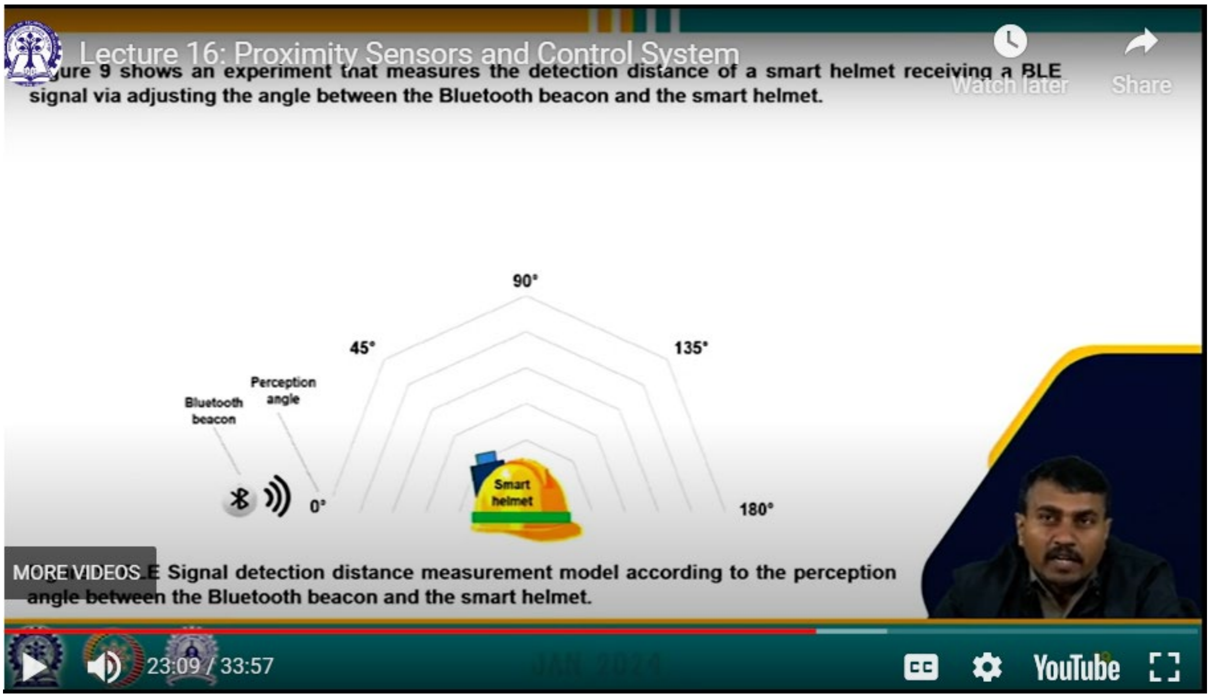
So, here the in two-dimensional three-dimensional figures is been attached with the pictures. So, here the smart helmets the Bluetooth beacons are been attached and installed to test the efficiency and efficacy of this system. And here the real mind maps is also is shown with the figure of this photo. So, the experimental result is like this the different situation been created and been tested. So, for example, so this is the vehicle it is moving and the operator some miners is working inside of it.



So, there is a distance that from the vehicle to this miner. So, based on different power with starting from 0 dBm minus 4 dBm minus 8 dBm minus 12 dBm minus 16 dBm with this different power these Bluetooth beacons was tested and their performance with the smart helmets beacon and the LED lights is been assessed. To test the efficacy that to how far with this signal strength this kind of system can be operated safely. So, the Bluetooth module that received the BLE signal was installed at the rear of the helmet and the Bluetooth module and the Bluetooth beacon attached to the vehicle were arranged to face other. The Bluetooth beacon attached to the truck approached the miner standing on a mine way transfer route 100 meter highway at a speed of 10 to 20 kilometer per hour.

The vehicle is running at 10 to 20 kilometer per hour. So, now we have to test the efficacy of the system the whether the Bluetooth beacon is switch on and giving the alert. So, that the miners working nearby will be alerted and he or she will be shifted from that particular site or else this vehicle will stop. So, we then measure the direction detection distance at which personnel the PWS receiving the BLE signal begun warning the worker. So, the TX power was set at 4 dBm interval.

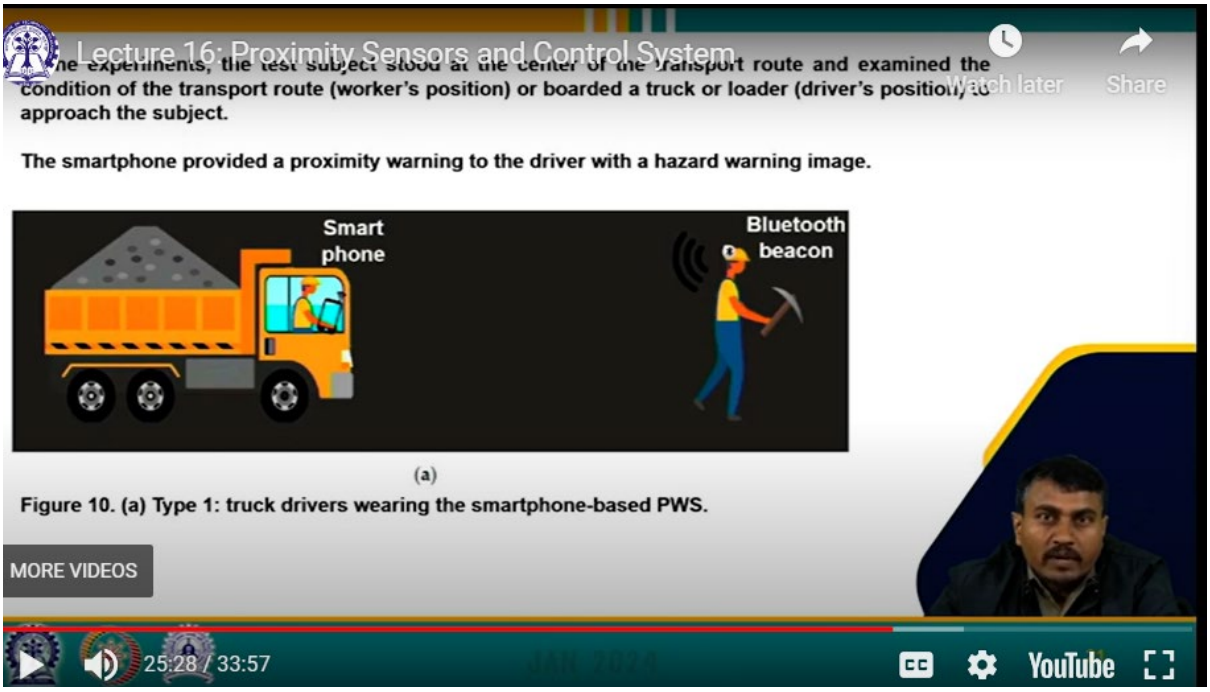
So, minus 12 dBm to 4 dBm and measure 10 times for each TX power 50 times total. So, it is the typically the signal detection distance measured main model according to the perception angle between the Bluetooth beacon and the smart helmet. So, at each 45 degree angle the measurement is been conducted and this kind of graph is been plotted. So, this figure shows the experiment that the measurement measures the detection distance of the smart helmet receiving a BLE signal by adjusting the angle between the Bluetooth beacon and the smart helmet. Similar to the above experiment, the truck approached at a speed 10 to 20 kilometers per hour and the detection distance at which the warning commands was measured.



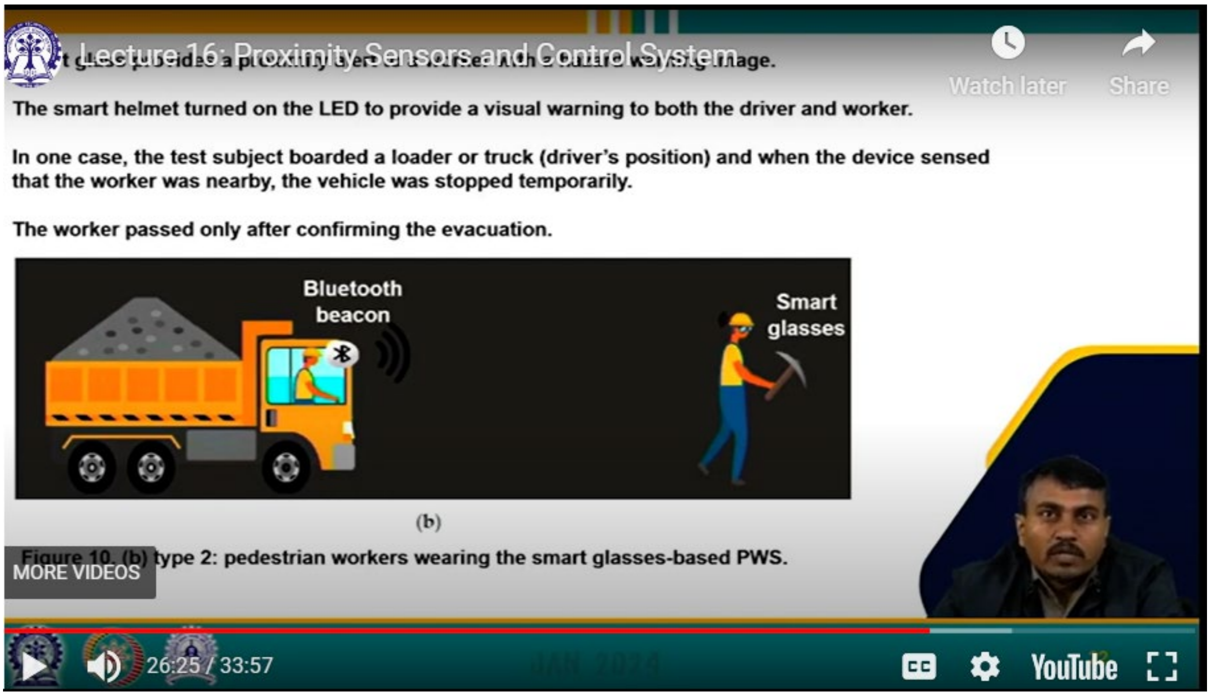
The angle between the smart helmet and beacons were set at 45 degree intervals from 0 to 180 degree and measure 10 times for each angle 50 measurement in total. Subjective workload assessment of smart helmet-based personnel proximity warning system. Three equivalent experiment were performed under the same experimental condition to compare the effect on subjective workloads. In this study the subjective workload evaluation was performed on 10 experimental subject aged 24 to 26 years old average age is 24.9 years at the same location where individual PWS performance was evaluated.

More than half that is 60 percent of the test subjects said they had knowledge of the smart glasses and the majority 80 percent said they had no knowledge of the smart helmets. The test subject used a smartphone based personal PWS driver positions, B a smart glass based personnel PWS workers position and C smart helmet based personnel PWS workers and driver positions. So, in the experiment the test subjects stood at the center of the transport route and examine the condition of the transport route workers position or boarded a truck or a loader driver position to approach the subject. The smartphone provides a proximity warning to the driver with a hazard warning image.

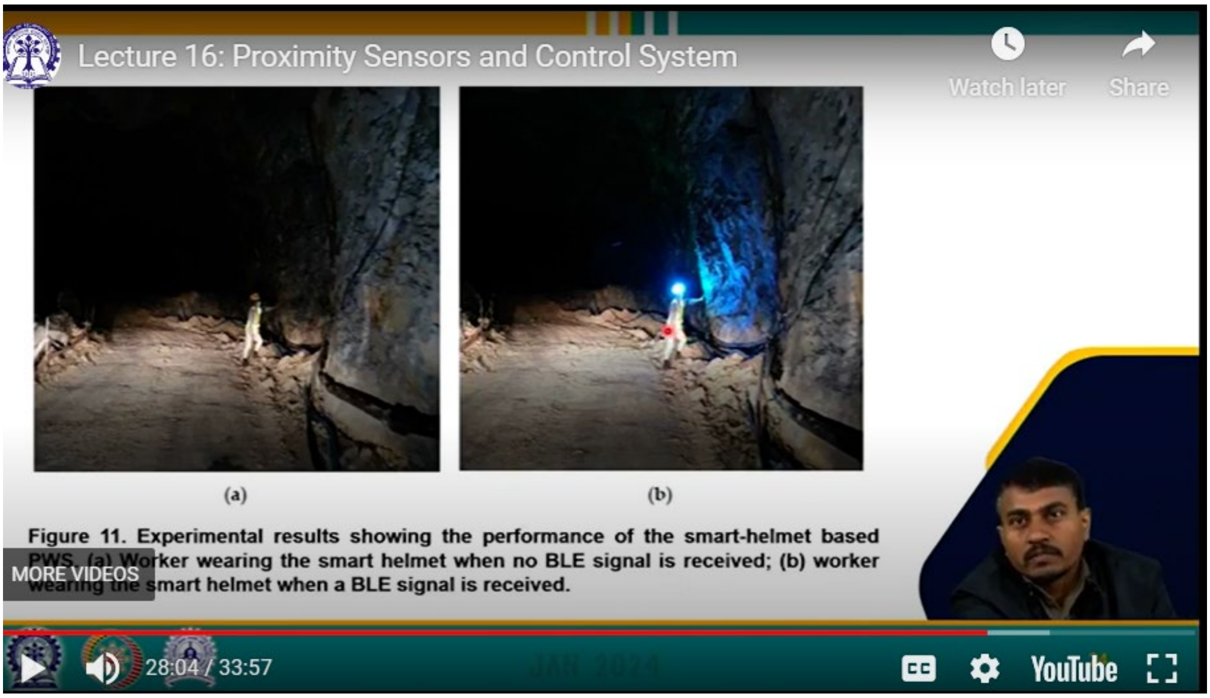
So, this is the typical image. So, when the truck driver wears the smartphone based PWS on the smartphone some warning is alerted that some worker is working in front of it. So, that is one way to alert that something is there and so that driver can take appropriate action to safeguard the workers that is working nearby. Smart glass provides a proximity alert to a worker with a hazard warning image. The smart helmet turn on LED to provide a visual warning to both the driver and worker. In one case the test subject boarded a loader or a truck driver position and when the device sensed that the worker was nearby the vehicle was stopped temporarily.



The workers passed only after confirming the evacuation. So, this is the part Bluetooth beacon and the smart glass were by the miners that is both getting the signal and the warning message once the workers shifted from that particular path only then the vehicle start moving. In another case the test subject examined the transport route maintenance status workers position and the operation was stopped when the device sensed that a vehicle was approaching. The subject evacuated to the side of the transfer route and only after the vehicle has passed did the operation resume. So, here the worker was working and he or she is working wearing the smart helmet and it received the signal that something is going on some vehicle is coming into the proximity.

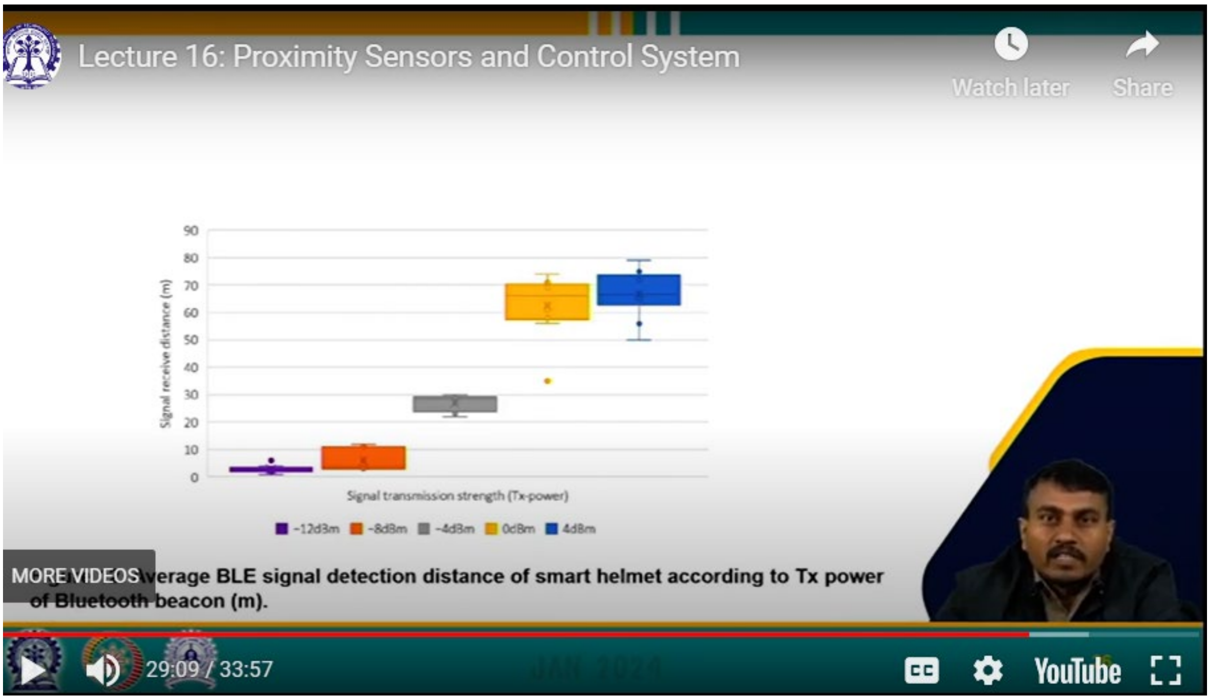


So, the workers stop the work and once the vehicle passed then again the work is resumed. So, in all these cases we have seen that the effectively the collision or the accident is averted efficiently using this system. So, this is the particular result on this particular figure if you see that the before the alert is on and after the alert is on. So, worker is working on the site without receiving any signal yet. Now, the worker is working, but it received the signal and LED is on.



So, that it giving the error it giving the signal that something is coming close to this particular worker. So, stop the work and let vehicle pass. So, effectively the safety is enhanced using this system. So, the result of the smart helmet. So, the figure we have already seen the workers wearing a smart helmet when the BLE signal is not received and the figure second figure that we have seen the workers wearing a smart helmet when a BLE signal is received.

The MAC address of the Bluetooth beacon 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 signal was received. So, the visual alarm through LEDs both the workers and driver can recognize the danger in advance and prevent accidents. So, this is the typical graph of the signal distance for the detection of the BLE signal and the helmet a smart helmet according to the TX power rating. So, here the 4 dBm power signal have the highest signal receiving distance around 70 to 80 meters. And the higher the value in the negative it is the lesser the distance it is covered.



So, the average detection distance is 2.9 meter in case of minus 12 dBm, 6 meter in minus 8 dBm and 27 meter in case of minus 4 dBm, 62 meter in case of 0 dBm and 66.9 meter in case of 4 dBm. So, this is basically the relation. So, as the TX power is increased the smart helmet BLE signal detection distance is also increased. So, BLE signal propagation in the underground mines have challenges particularly the 90 degree inclined crossing curved sections that will impede the line of sights.

Environmental factors also have some challenges the rough mining wall causes signal diffraction and reflection, the rock mass lead to the radio signal attenuation that also a problem, high humidity and suspended dust is also a problem for this kind of system to operate efficiently. Electromagnetic interference power supply installation creates electromagnetic field and that is potentially interfere with the BLE signal. So, that is an issue that we have to resolve. Testing objective assess this signal stability in a complex mine environments and we have to understand the diffraction, reflection and interference effect and based on that the design to be customized. Testing importance, we have to enhance the communication or reliability in the mines and inform design for robust BLE system is required.

The advantages of this system and visual proximity alerts on smart helmets ensure quick identification of danger without disrupting work. Comfort and compatibility, it overcomes discomfort caused by smart glasses for workers wearing regular glasses or experiencing slippage. Workers with regular glasses, industrial goggles and soundproof headset can use smart helmets comfortably. Ease of use simplifies operation compared to existing PWS requires touchpad controllers and NASA TLX test indicates user finds smart helmets based PWS more convenience. Cost effective implementation, it utilize the Arduino and open source of source hardware reducing system cost allow for the distribution of multiple smart helmets and Bluetooth beacons make it adaptable to mines of various sizes.

Quick evacuation capabilities, facilitate rapid evacuation by providing visual proximity alerts without rock work interruption, enhance 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 size due to its cost-effective design.

So, these are the references.

Let us summarize in few sentences what we have covered in this lecture. So, a proximity sensor is a device that detects the presence or absence of an object or a person with a certain range without any physical contact.

So, we have discussed with an example, the utility of proximity sensing system to enhance worker safety in the mines using smart helmets. The result are optimistic and shows that it can be customized and mine specific needs may be served very well.

Thank you.