EYESENSE Project
Haptic feedback

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***Abstract*—This document presents the project done in the context of the ME-410 class. It consists in the design and the prototyping of a haptic feedback belt with an ultrasonic sensors collar. The belt indicates at the same time the direction and the distance of the nearest obstacle captured by the sensors. This device, named EYESENSE, has been evaluated in three different scenarios and proved its efficiency in multiple situations.**

***Index Terms*—haptic feedback, smart belt, Arduino, visually impaired person.**

I. Introduction

ARound 4% [1] of the Swiss population is visually impaired, according to the UCBA (Union Centrale Suisse pour le Bien des Aveugles). To displace, these people usually rely on a cane, which gives a limited range of detection, not only in terms of distance, but also in terms of direction. Thus, a solution to improve the environment perception for blind people would be of great use.

II. State of the Art

There are already existing haptic feedback devices designed to help blind people to navigate. For example, the *weWALK smart canes* [1] have extra functionalities such as horizontal detection. In addition, some wearable devices as *the wearable BuzzClip* [2] can be clipped on clothes and be used as detectors.
However, most of the existing aids are designed to detect the presence of waist or head level obstacles in a specific direction. In order to complete the cane, it would be interesting to develop a device that allows its user to have a multidirectional vision (360°) of their environment. In addition, the device would be more useful if it could have a sense of the distance using haptic feedback.
From these considerations, the EYESENSE project is defined. It consists in:

- A wearable device
- 360° environment sensing + 360° tactical feedback
- Feedback intensity varies with distance to obstacle

More than that, a design challenge of EYESENSE was also to focus on dissociating the communication of direction and distance in order to allow the user to better perceive and distinguish these two different inputs.

This project has been done with the help of the EPFL RRL Laboratory.
This paper has been submitted on the $24^{th} December 2021$

III. Specification Table

In order to provide performance requirements of our device, we defined engineering specifications. These metrics are crucial, since they quantify specific characteristics of the product with measurable criteria, to meet satisfaction. We divided our specifications into three different categories: detection, actuation and wearability. All metrics are showed in the tables below.

Constraint	Target	Threshold
Range of detection	3 m	Min 1.5, max 6m
Angle of detection	360 deg	-
Detection environment*	Dust, smoke, fog, dim	-

TABLE I: Metrics of detection

Constraint	Target	Threshold
Push/tightening force	20N	Min 10N, max 30N
Angle of actuation	360 deg	-
Actuation proportional to the distance	Adjustable displacement or rotation frequence	-

TABLE II: Metrics of actuation

Constraint	Target	Threshold
Belt compactness	Height 8cm Width 5cm	Height max 12,5cm Width max 10cm
Belt adjustability	Adjustable length between 60cm and 80cm	Min length 60cm
Collar compactness	Height 4cm Width 3cm	Height max 7cm Width max 5cm
Collar length	Depending on the chosen solution : between 30cm and 80cm	Min 32cm Max 90cm
Total weight	2 kg	Max 5 kg
Noise*	-	Max 97 dBA

TABLE III: Metrics of wearability

Here are some details about the main specifications we defined:
We estimated that a range of detection of 3m would allow blind people to perceive obstacles soon enough to be able to avoid them, while displacing with a normal walking speed. Giving more distant obstacles feedback would overload the user with unnecessary information of the surrounding. The 360 degrees

of detection and actuation are the essence of the project. A normal person is able to see in any direction, by rotating his head, and this is the ability we look to offer to the user of the device. To be able to feel the tightening of the belt, we estimated, with real life measurements (dynamometer), that a force of 20N was needed. We also measured that above 30N, the tightness was starting to hurt the user (adult person), which is something we totally want to avoid. Many dimension specifications were also defined, since we want our device to be wearable, adjustable to different sizes and also compact enough not to disturb the mobility of its user.

All the metrics come from ME-410 course project engineering specifications and real life measurements.

IV. Design Selection

In order to meet the set specifications, different solutions have to be explored in terms of sensors, actuators and overall mechanical design.

A. Detection

To detect the obstacles, ultrasonic sensors seem instantly to be the best solution. Indeed distance sensors are not affected by object colors, transparency and detect obstacle within an angle range. In addition, the speed of the sound makes the ultrasonic sensors fast enough for a walking person. However, attention should be paid to sound wave interference between the sensors and with the surrounding.

B. Actuation

To indicate to the user the detected obstacles, three different actuation solutions are developed: the *vibrator*, the *shell* and the *crick*.
The vibrator consists of vibrating motors that vibrate in order to indicate the presence of the closest obstacle.
The shell is a device that sinks into the skin by rotating more or less in function of the distance of the obstacle. Each shell uses a servomotor.
The crick sinks into the skin too but works like a jack instead of rotating. Each crick uses a stepper motor.
Now that these three solutions are defined, they can be compared.

First, the number of possible feedback proportional to the distance varies significantly between the vibrator and the solutions that sink into the skin. We estimated that the shell and the crick can not go deeper than 1cm into the skin. Moreover, the minimal perceptible change in sinking is estimated to be around 2mm. By considering these two estimations, the shell and the crick have only five possible positions for giving a distance feedback. On the other hand, the vibrator can easily give 100 different feedback by changing the vibration intensity.
Furthermore, the belt has to be compact and light. The vibrator solution seems to be the best idea to meet this specifications. Indeed, the shell requires several servomotors while the crick requires multiple stepper motors.

Finally, blind people often use their audition to locate and navigate into the space. Thus, the last main choice criterion is the noise of the actuators. However, the noise emitted by each of the three solutions can be below an inconvenience state. Thus, this criterion is not eliminatory.

By considering these main criteria, the choice to select the vibrator solution for the EYESENSE project is done.

C. Wearability

For the wearability, we choose to have an actuation belt and a detection collar.
The actuators are placed around a belt and the belt is placed as a regular belt. Indeed, with this placement, the belt is not impacted by the user's respiration and there is no need to think about the user's morphological specification apart from the waistline.
The sensors are placed on a collar. In this way, the obstacle detection is not disturbed by the user's arms detection. In addition, the shoulders are one of the most stable body parts, which is important for sensing the environment.

V. Optimization of the solution

Now that the solution is defined, a possible problem appears: will it be easy for the user to feel and quantify changes in vibration intensity? Will he get used to vibrations and not feel them anymore? This problem leads to our solution optimizations.

After some iterations, an optimized solution emerges: a tightening belt. This new solution consists in using the vibrating motors only for indicating the nearest obstacle direction while using the belt tightening to indicate the distance from this obstacle. With this solution, the intensity of the vibrating motors is no longer modulated.
The positive aspects of this optimized solution are the increase of sensitivity for the user and the ease of use while dissociating the information of direction and distance. In addition, the fact that the belt tights itself and adapts to the user's position and posture, even when there is no obstacle, is an additional comfort.
However, this solution complicates the device and removes the perception of all obstacles in a radius around the user: EYESENSE can only indicate the nearest obstacle anymore.
By weighing the pros and cons, this optimized solution is retained for the EYESENSE device.

VI. Prototyping

As displayed in Figures 1, the final design of the prototype is composed of three distinct parts:

- Collar
- Belt
- Bag

Each part serves a particular purpose. We used the Collar for the detection of the obstacles, the belt for the transmission of the surroundings to the user using haptic feedback and the

(a) Back (b) Front

Fig. 1: Final prototype

bag regroups all the connections, the power supply, and the Arduino.

A. Collar

1) Location: As mentioned before, we use a collar for detection. It is worn in the upper body and has two main advantages.
First, the prototype is not a replacement for the cane and must therefore enhance the volume of detection of its user. In fig. 2 one can notice that the cane mostly detect obstacle forward at the bottom of the user. The role of EYESENSE would be to obtain a full volume of detection of 360° top to bottom. However, the prototype aims to give a proof of concept and therefore reduces the problem of obstacle detection at 360° of the user's top part. This zone was carefully selected as the most critical region of detection not covered yet by the cane. With top detection, the user can take advantage of both the prototype and the cane to detect all obstacles that are coming from his front. At the same time, most of the dangerous obstacles coming from the side or behind are usually tall enough to be detected at the level of the collar. Therefore, the plus-value obtained by EYESENSE is maximized even with a partial volume of detection.

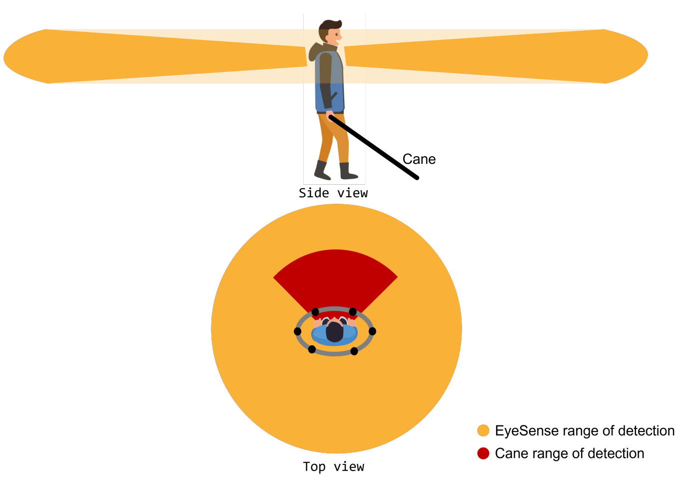

Fig. 2: Volume of detection

Second, the clearance in front of the sensing. The project had for objective to not be uncomfortable to wear and should not perturb the locomotion of its user. However, placement of the detection on a lower part of the body between the hips and the shoulders was not possible due to the possible obstruction of the detection with the arm balancing on both sides of the body. The two locations left were the shoulder and the head. However, since the detection has to be coupled with the haptic feedback at the belt, we chose the shoulders. They are more or less aligned with the hips at all times when on the other hand, the head can rotate and not be aligned with the hips axis. On top of that, it is less invasive to wear something on the shoulder than on the head.

2) Components: The collar is composed of 4 elements :

- 1 Support collar
- 7 Ultrasonic sensors
- 7 Direction adjusters
- Cables

The **support collar** maintains all the other components on the shoulder of the user. Initially used by the hairdressers, it is easily adjustable to the user's shoulder with only a pair of magnets (see fig. 3). This simple solution was perfect in terms of its compactness, lightweight, and capacity to adapt to every shape.

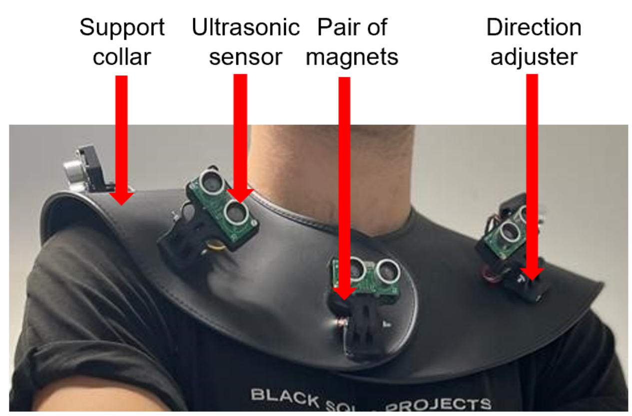

Fig. 3: EYESENSE first prototype

The **7 ultrasonic sensors** are put all around the support collar to cover every direction (see fig. 4).

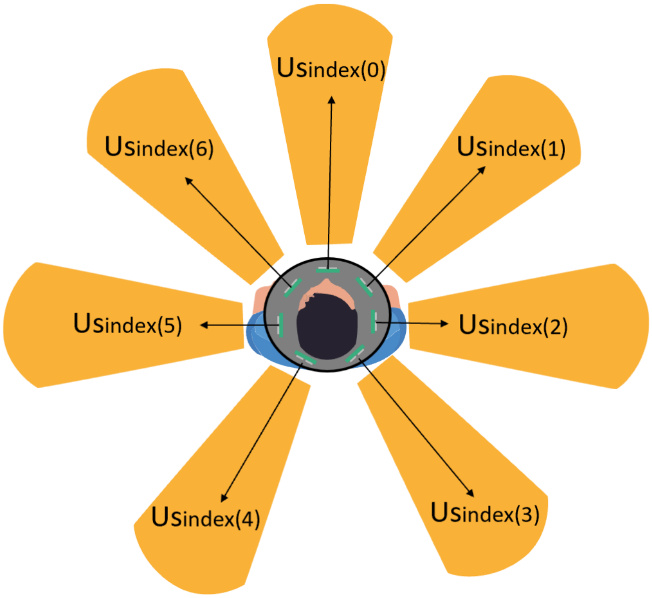

Fig. 4: The ultrasonic sensor placement on the collar

They are all Us-100 sensors. This sensor has several characteristics as mentioned in table IV.

Power & Logic Voltage	DC 2.4V∼5.5V
Current	2mA
Operating Temperature	-20∼+ 70°
Measuring Angle	∼15°
Detection Distance	2cm - 450cm
Accuracy	0.3cm +1%
Sensor dim.	45 x 20mm
Weight	9g

TABLE IV: Ultrasonic sensor (US-100) characteristics

They are all used in "UART" mode and use 9600 baud UART to communicate with the control board. This sensor possesses five pins :

- 1 Trigger
- 1 Echo
- 1 VCC
- 2 grounds

VCC and the ground are connected to the power supply. The trigger and the echo pin are respectively connected to an output and an input pin of the control board. This one can start measurement by putting the trigger pin to 0x55 and waiting back the 2 bytes of the echo pin that encapsulate the measured distance in millimeters. More precisely, when the trigger pin receives a pulse of more than 5 [us], the echo pin sends back the measurement as a pulse width that corresponds to the time of flight of the sound from the ultrasonic sensor to the object and back. Therefore the distance from the object can be computed by :

$$Distance = \frac{PulseWidth \cdot SpeedOfSound}{2} \tag{1}$$

A pulse width value greater than 60ms indicates an out of range condition [3].
The **7 direction adjusters** are essential to adjust the pointing direction of each sensor parallel to the floor (see fig. 5). The support had to be lightweight, compact, and easy to adjust. This was realized with a design inspired by the fixation of the well-known GoPro camera and is composed of two pieces. They are attached using a screw and a slight tightening. This way, the direction of the ultrasonic sensor screwed on the top part can be easily adjusted.

Fig. 5: Direction adjuster

All the **cables** are connected to the ultrasonic sensors and hidden underneath the collar. They all converge to the back of the collar.

B. Belt

The belt is composed of 3 principal components: the tightening mechanism, the load cell and the vibrators. Each component has its specific purpose, which are the following:

Tightening the belt
The pressure on the waist applied by the belt informs of the distance of the nearest obstacle. After exploring several solutions, we decided to use a thread shaft motor mechanism in order to tight the belt. In fact, the thread acts as a mechanical reducer and allows to reach the high forces specifications we are targeting. In addition, this mechanism is able to maintain the internal traction of the belt without using the motor energy, as the thread acts as a position holder. For our prototype, we used the screw mechanism of a hose clamp, since it is a cheap and accessible product and has a rounded and flexible flat threaded metal strip, contrary to a standard thread shaft motor which is a rigid threaded rod. For connecting the motor [4] to it, we designed and 3D printed some mechanical parts that allow the motor to be fixed on the metal strip and to transmit its rotation to the screw of the hose clamp. The mechanism is showed in the figure below.

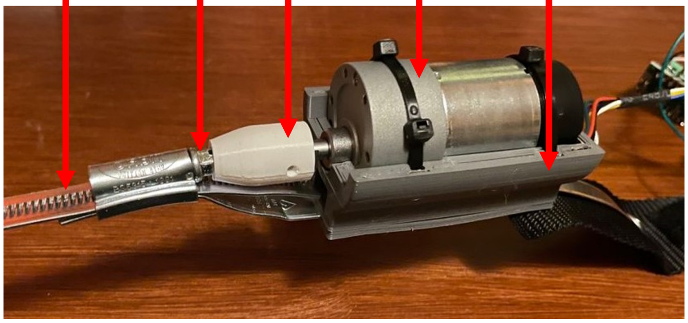

Fig. 6: Motor transmission

Some calculations were done to estimate the necessary torque and speed of the motor to be able to apply the 20N tightening force targeted in our specifications (See Appendix 1). However, many variables were unknown at the moment of the motor dimensioning, such as the hose clamp thread pitch, the internal friction of its screw box or its lubrication. Therefore, we decided to select an over-dimensioned motor (Pololu gearmotor of 1.5Nm torque, 330rpm, 24V) to be sure to reach the needed torque and speed. A motor driver is also used to supply the 24V voltage and allow the Arduino to control the speed and direction of the motor.

Measuring of the tightness

The angular position of the motor is not directly linked with the tightening of the belt, because of many variable factors, such as the waist circumference of the user, the force applied on the belt when putting it on, or even the softness of the human body. For these reasons, we need a continuous measure (feedback) of the internal traction of the belt to precisely control its tightening. Many options were considered (motor current sensing, FSRs, strain gauge, compression or traction load cells) and the parallel beam load cell was chosen. This sensor offers a wide range of measure as well as a high precision. load cells are cheap and easily accessible sensors, mainly used for scales. We purchased a load cell [5] for maximum loads of 5kg to fit our tightening force specification of 20N. For the tightening measurement of the belt, we had to customize the load cell, as we apply horizontal forces on it, which is not the way we usually use it. Some L-shapes were designed, 3D printed, and screwed to the load cell. This way, we were able to attach the belt to the load cell from both extremities, using 3D printed buckles.

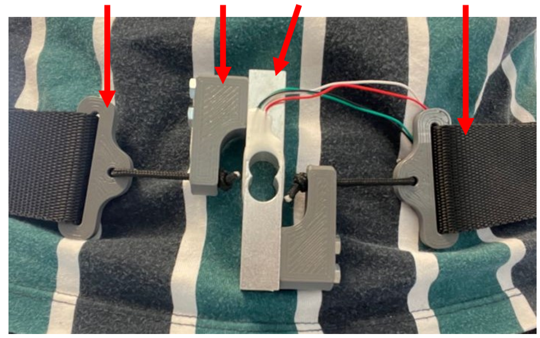

Fig. 7: load cell

The load cell is used with a load cell amplifier to be able to read the very low resistance variations of the sensor. Before including it to the belt, some test of calibration were done in order to get the calibration factor, which is the constant that directly relies the output signal of the load cell to the applied traction force in Newtons (See Appendix 2). The figure below shows the configuration of the load cell with the belt.

Direction indication

The nearest obstacle direction is transmitted through the use of vibrators. To that end, seven vibrators are positioned all around the belt. One of the most important criteria for choosing the vibrator is how intense is the feeling, the sensation it offers, and this is something that is hardly measurable. Therefore, we purchased several vibrators which met our belt compactness specifications and tested them to choose the most appropriated one. We could observed that the feeling intensity was not necessarily related to the speed (rpm) of the vibrator motor. The seven vibrators [6] were finally attached to the internal side of the belt with scratches for modularity. This enables to reposition the vibrators if necessary to adjust them to the user's waist size.

C. Bag

1) Location: The bag brings together all the cables and supports all control electronics. It is situated between the collar and the belt to simplify the connection. However, this part will disappear in the next iteration and only serves for the practicality of the prototype. At term, all the control and power supply will be encapsulated in one of the two other modules e. i. the belt or the collar.

2) Component: The bag contains four elements:

- 1 Arduino Uno
- 1 shift register
- 1 motor driver
- 1 load cell amplifier
- Cables

The **Arduino Uno** is the control board of the prototype see fig. 8 . It uses an ATmega328P and possesses 14 digital input/output (of which 6 can be used as PWM outputs), 6 analog inputs, and a 16 MHz ceramic resonator. A USB connection is available to simplify the connection of the board with a computer (for more details on the board, see [7] or directly the data-sheet [8]).

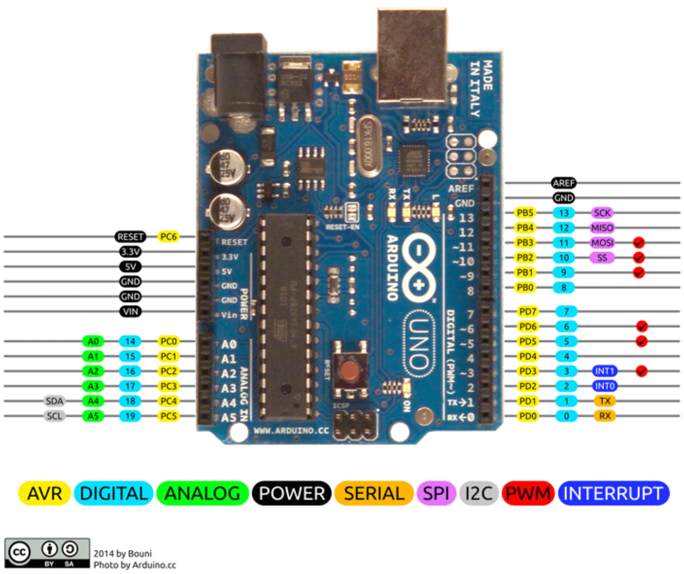

Fig. 8: Arduino Uno with all pin's characteristics

For this project, the number of pins of the Arduino Uno was critical due to the extended number of actuators and sensors. To minimize the use of pins, a **shift register** was used and connected every vibrator to the board using only five pins:

- Serial data input
- Latch pin
- Clock pin
- VCC
- Ground

The shift register has the advantage to connect several outputs with only one input. Therefore, it helps control all the vibrators individually in a simple manner. First, the latch pin has to be set to low to be able to update the shift register. Second, activate or deactivate the bit of each vibrator in the byte that will be sent to the shift register (for example 11000010 will activate vibrator numbers 0,1 and 6). Third, shift the data to the shift register. Fourth, set back the latch pin to high.

The **motor driver**, the **load cell amplifier** and the ultrasonic sensor's **cables** are all connected directly to the board. Almost all the pins are used. The analog pins are used as digital to take full advantage of all the pins of the board (see fig. 9).

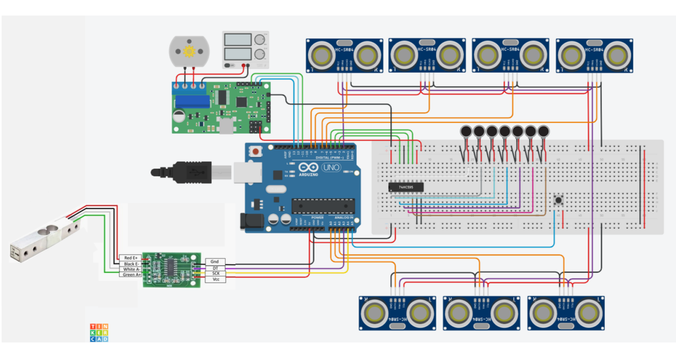

Fig. 9: Electric diagram of the prototype

D. Control and operation

As mentioned before, the goal of the prototype is to help the user navigate while avoiding all the static and dynamic obstacles in its surrounding. An efficient way to achieve this objective is to signal only the direction and the distance of the nearest obstacle. This way, we assume that the user should concentrate its attention on the most urgent thread e.i. the closest obstacle.

Moreover, the duration of a cycle has to be reduced to the minimum to guarantee a good reactivity of the prototype.

A typical cycle applies the following four steps:

1) Detection of the closest obstacle with ultrasonic sensor
2) Read load cell value
3) Apply P-controller
4) Update motor speed and vibrator selection

Firstly, the detection of the closest obstacle with the ultrasonics sensor is the most critical part of the cycle in terms of duration and reactivity. To derive the closest obstacle, all the ultrasonic sensors have to update their measurements. This is a strong limitation considering that this type of sensor uses the speed of the sound to measure the time of flight of an ultrasonic wave. Additionally, the sensors can not be all triggered at the same time and need to sequentially send a signal and wait for the echo during a maximum duration of 100ms which represents a maximal distance of detection 17m (1). This waiting time can not be lowered without a significant increase in the "out-of-bound" measurements. However, the waiting time could be meaningfully decreased with the help of external interrupts which would only require the board when a new measurement would be signaled. Unfortunately, Arduino Uno only includes two of them. Hence, the maximum time a full cycle can take (no obstacle detected), is around:

$$7\,[ultrasonicsSensor]\cdot 100\left[\frac{ms}{ultrasonicsSensor}\right] = 700[ms] \tag{2}$$

When all the measurements are collected, a simple algorithm derives the value and the index position (US_{index}) of the ultrasonic with the closest obstacle. This distance value is then used as a reference V_{ref} in the control loop (see fig. 10).

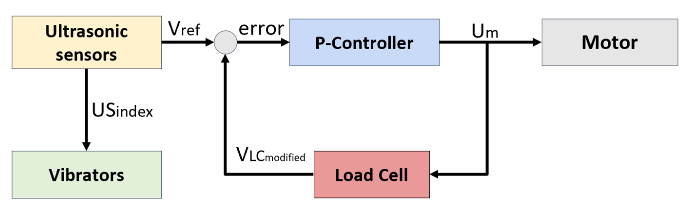

Fig. 10: Control loop of the prototype

Second, the measurement of the tightening is updated with the load cell. However, this value in Newton has to be transformed into meters to integrate the control loop. For this purpose a simple ratio of the ranges of both sensors is multiplied by the measured value :

$$V_{LC_{meter}} = ratio \cdot V_{LC_{Newton}} \tag{3}$$

with

$$ratio = \frac{MaxUS - MinUS}{MaxLC - MinLC} = \frac{RangeUS}{RangeLC} \tag{4}$$

The corresponding value of the ultrasonic sensor (US) and the load cell (LC) are respectively $MinUS = 0$ [m], $MaxUS = 3$ [m], $MinLC = 1$ [N] and $MaxLC = 18$ [N]. These ranges are chosen to satisfy the specification of both the prototype and the sensors. The minimum of the load cell is chosen to 1 [Newton] to maintain the belt in the user's hips.
Thirdly, the error is derived and applied to a P-controller. However, to compute an error that makes the belt tighter with close obstacle and not the opposite, the load cell measurement in meters has to be subtracted from the maximum value of the ultrasonic sensor :

$$V_{LC_{modified}} = (MaxUS - V_{LC_{meter}}) \tag{5}$$

This makes the relation between the ultrasonic and the load cell sensor proportional. Then, the error can be derived as follow:

$$error = V_{LC_{modified}} - V_{ref} \tag{6}$$

Then the motor input U_m can be computed with the P-controller as follow:

$$U_m = error \cdot K_P \tag{7}$$

With $K_P = 200$ the proportional gain of the controller. This value was fine-tuned by multiple experiences and was a good compromise between high reactivity and little steady-state error. The steady-state error is not a big problem in our application since we assume that the system constantly adapts to the environment with a continuously floating reference.
Fourthly, the motor input U_m is clipped to the motor amplitude and sent to the motor driver. The vibrators are activated or deactivated in function of the update of the ultrasonic sensor with the smallest distance value (US_{index}) as shown in fig. 11. If no ultrasonic sensor measured a value under 3 meters, all the vibrators are set off at the end of the corresponding cycle.

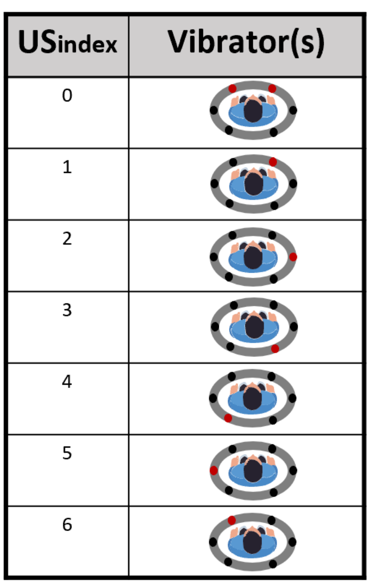

Fig. 11: Activation vibrator in function of US_{index}

VII. Performance

A. Engineering specifications

Engineering specifications are recalled to compare them to the actual characteristics of the prototype. In Figures V and VI, it can be seen the detection and the actuation constraints are respected.

Constraint	Target	Threshold	EYESENSE
Range of detection	3 m	Min 1.5, max 6m	3m
Angle of detection	360 deg	-	360 deg

TABLE V: Verified metrics for the detection of EYESENSE

Constraint	Target	Threshold	EYESENSE
Push/tightening force	20N	Min 10N, max 30N	18N
Angle of actuation	360 deg	360 deg	360 deg

TABLE VI: Verified metrics for the actuation of EYESENSE

Figure VII shows the wearability side, a lot of dimensional constraints for the belt and the collar had been defined, which were respected. Furthermore, the total weight was an important constraint for wearability. Two times less weight than what we expected to have been obtained. The noise is also acceptable but not perfect due to the motor and vibrators noise.

Constraint	Target	Threshold	EYESENSE
Belt compactness	Height 8cm Width 5cm	Max height 12,5cm Max width 10cm	Height 8,5cm Width 8,5cm
Belt adjustability	Adjustable length between 60cm and 80cm	Min length 60cm	Max length 100 cm
Collar compactness	Height 4cm Width 3cm	Max height7cm Max width 5cm	Max height 6cm Width 15cm
Collar length	Depending on the chosen solution : between 30cm and 80cm	Min 32cm Max 90cm	44 cm
Total weight	2 kg	Max 5 kg	930 g
Noise*	-	Max 97 dBA	69dBA

TABLE VII: Verified metrics for the wearability of EYESENSE

B. Proof of concept

Scenario

Three situations were simulated: 1) Avoid dynamic obstacles; 2) Avoid static vertical head level obstacles. The main objective of all situations is to walk through a corridor avoiding obstacles. The obstacles are rectangular white panels. For the dynamical situation, they are held by the team members which move forward the blind participant. For the static vertical obstacle situation, the obstacles are fixed on the floor. And finally, for the static head level obstacles situation, the obstacles are held horizontally by the team members. During each test, a screen displays the values detected by the ultrasonic sensors and the load cell as well as the commands sent to the vibrators and motors. In addition, an interactive interface has been created in order to be able to better visualise the distances detected by each ultrasonic sensor, the activated vibrator, the motor speed and direction of tightening and the force detected by the load cell. Moreover, a stop button permits to stop the program for safety. This interface is displayed in Figure 12.

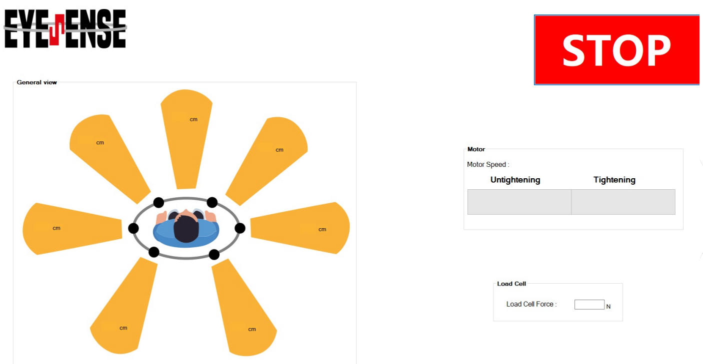

Fig. 12: Interactive interface

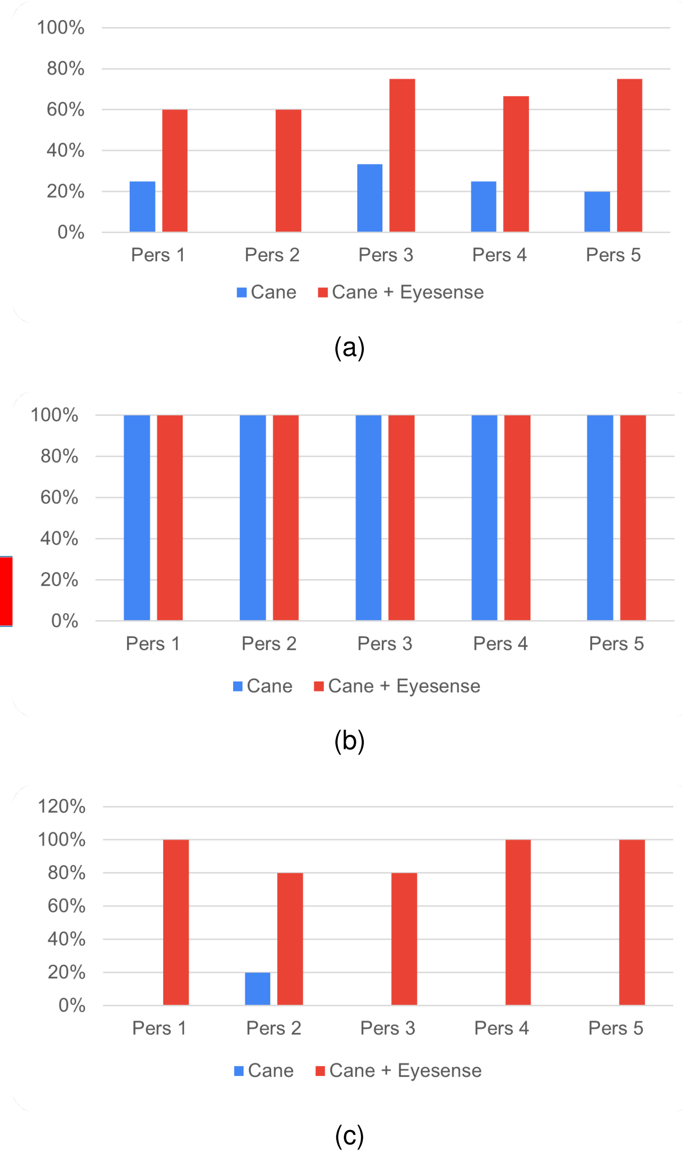

Fig. 13: Individual proof of concept results. (a) and (b) are respectively the percentage of avoided moving obstacles and the percentage of avoided static vertical obstacles. (c) is the percentage of avoided static horizontal (head level) obstacles.

Participants are the group members in turn blindfolded. The two situations wanted to be compared for each scenario are : 1) only with a cane; 2) with a cane and the EYESENSE device. Finally, the performance criterion consists in comparing the percentage of obstacles avoided with a cane and with cane plus EYESENSE. The percentage in each case will be averaged on several rounds and several persons to avoid bias

Individual results

In Figure 13, the results for each person and each of the three situations are displayed. Note that the results for each person are averaged on different rounds. What it is essential to highlight here is that the results are stable through trials. This can be quantified by computing the variance, which is of maximum order of 10^{-2}.

Averaged results

The averaged final results are displayed in Figure 14. What can clearly be seen is that the usefulness of the device depends on the situation. First, it's evident that in the static vertical situation our device does not increase the performance as a blind cane is exactly fitted to this kind of obstacle. On the other hand, the other two situations clearly demonstrate the effectiveness of the prototype. On the dynamic side, EYESENSE allowed to improve the performance by three because the lateral and back obstacles can not be detected by the cane. On the static horizontal (head level), EYESENSE performs ninety times better than the cane alone because the cane can't detect obstacles not touching the floor. Moreover, the prototype is well configured, as the ultrasonic sensors are placed at the head level and the bigger surface obstacles increase detection.

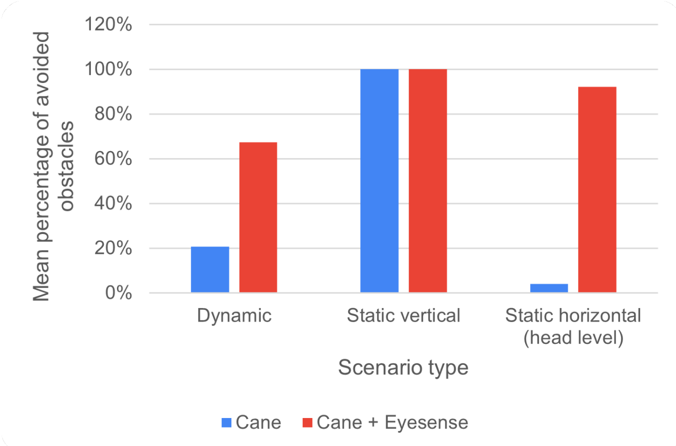

Fig. 14: Averaged proof of concept results

Qualitative pro and cons
A good point of wearing the device is that the participants were less afraid of moving forward because they were able to anticipate obstacles as if they could see them. On the other hand, the first time participants tested EYESENSE, they had the feeling to receive too much information simultaneously. To take advantage of the entire potential of the prototype, some trials are needed, participants have to be more used to it.

Bias
However, it's important to recall the possible bias of this performance analysis. The main limitation is that the tests are not done in a real environment. In fact, there will be many more obstacles, and static and moving obstacles at the same time in real life situations. Also, it's expected that if the device was tested on blind people, it would be more effective as they are used to the darkness. Participants had very little time to test the device, with more experience it's expected to obtain even better results. Finally, the tests were carried out with a stick instead of an official blind cane. The movement that can be carried out with this one is much less smooth than that which can be done with a real cane. This makes the detection scenario with the rod potentially less efficient.

VIII. Problems Faced

The main problem of the prototype is reactivity. This was due to the impossibility to use external interrupts for the ultrasonic sensors, because unfortunately the Arduino Uno only have 2 external interrupts. Moreover, the speed of tightening was low due to the slow motor and the screw thread. Also, the ultrasonic sensors are slow because their signal travels at the speed of sound.
Another limitation is the non perpendicular detection. In fact, the sound waves sent by a ultrasonic sensors are just deviated in the case of diagonal obstacle and will not go back to the ultrasonic sensor as it is illustrated in Figure 15.

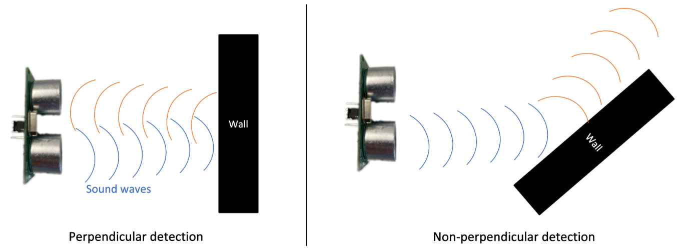

Fig. 15: The ultrasonic sensor wall detection

In terms of tightening, it was sometimes difficult to distinguish the difference in tightening and therefore the participants had difficulty distinguishing the difference in distance.

IX. Future Improvements

To improve the reactivity, the use of external interrupts for the ultrasonic sensors is a must have. Moreover, a smaller screw thread could help because this allows to move forward a greater distance in less time.
A different sensor type (whose signal travels at the speed of light) could also help on this point and it would permit to detect diagonal objects.
An even more useful characteristic of the device would be to give feedback for more than only one obstacle (not only the nearest obstacle). Furthermore, increasing the ultrasonic sensors number and resolution would make the prototype more accurate.
A waterproof device would be very appreciated to be able to use it under rain conditions. If the device would make less noise, it could used during longer periods of time.
The overall design, including connectivity, wearabiliy, belt statics, could be improved. For example, a Bluetooth transmission between the belt and the collar could be set up in order to make the device more easily wearable. Also, integrating the control processor (here the arduino) in one of the two modules (belt or collar) would permit to not need a bag linking the two, which is an advantage for wearability.

X. Conclusion

Finally, EYESENSE first prototype works. Its performance has been proven according to different scenarios that focus on the situations in which the device is most useful. Despite the fact that some improvements can be implemented, the prototype already has potential in the market since it provides the 360° view, which does not exist among competitors.
The prototype could also be used in emergency conditions without a clear vision as firefighters in burning buildings or in military/police applications.
Another possibility is to adapt EYESENSE for the entertainment domain. The device could be integrated in video games and in virtual reality experiences. Finally, sports as cycling or scuba diving could be another path to explore with EYESENSE.

Acknowledgments

We would first of all like to sincerely thank Professor Jamie Paik for giving us the opportunity to realize this project and prototype. Thank you to all the doctoral assistants of the course for their advice. Finally, we also want to thank the Reconfigurable Robotics Lab and the Mechanical Engineering section for the resources provided.

CODE AVAILABILITY

The code used for the prototype and the interface is provided on the following Github repository: https://github.com/PacM-6610/EyeSense

APPENDIX

Appendix 1 : Equations used to compute the torque of the motor

Average diameter screw thread :

$$P = \pi \cdot d_2 \cdot \tan \alpha_2$$

Averge diameter :

$$D_2 = d_2 = d - 2\frac{3}{8}H \approx d - 0,64952P$$

Apparent friction angle :

$$\delta' = \tan^{-1} \mu'$$

δ'	[rad]	apparent friction angle
μ'	$[-]$	apparent dynamic coefficient of friction screw-nut

Coefficient of apparent friction :

$$\mu' = \frac{\mu}{\cos(\beta/2)}$$

μ'	$[-]$	apparent dynamic coefficient of friction screw-nut
μ	$[-]$	dynamic coefficient of friction screw-nut
β	[rad]	opening angle of the net

Clamping force :

$$F_{US} = F \tan(\delta' + \alpha_2)$$

F_{US}	[N]	clamping force
F	[N]	downforce
δ'	[rad]	apparent friction angle
α_2	[rad]	angle of rise of the thread on the average diameter

(8)

Tightening torque due to thread-nut friction :

$$M_{FS} = F_{US}\frac{d_2}{2}$$

M_{FS}	[N m]	tightening torque due to thread-nut friction
F_{US}	[N]	clamping force
d_2	[m]	average diameter

(9)

Appendix 2 : Load cell calibration

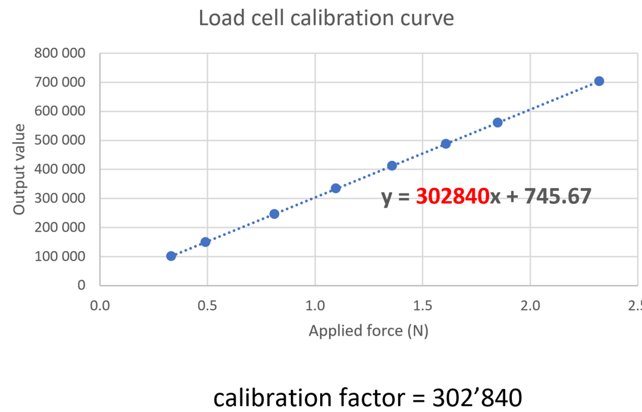

Fig. 16: Load cell calibration curve

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