LED Strip Based Robot Movement Intention Signs for Human-Robot Interactions

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***Abstract*—As a new kind of robots, called cooperative robots, are more commonly used in industry, a new way of communication is becoming more important due to the increasing number of closer cooperation between human and robots. This paper proposes the idea behind a novel method of using visual communication between cobots and humans focusing mainly on the field of industrial robotics. This device can decrease the mental stress experienced by the coworker and can increase the trust resulting in a closer to ergonomic workspace from the coworker viewpoint. Other possible usage is also discussed.**

***Index Terms*—human-robot interaction, robot feedback, visual feedback, cooperative robotics, cobot**

I. Introduction

Humanity has reached the point in the technical development when simple repetitive processes can be passed to robots so most of the boring, dangerous or unergonomic processes will not threaten humans.

Robotics has overcome a long distance in its evolution from the first appearance of the word "Robot" in science fiction drama of Karel Čapek in 1920 through Robert C. Devols Unimation, the worlds first industrial robot, to nowadays when the robots, both industrial and social, are becoming everyday part of our lives [1].

In [2] the following key points were conducted from the meta analysis regarding to trust in human-robot interactions (HRI). The main influence on trust is the robot's characteristics and performance. Moderate factors are the environmental factors on trust and a small role is given also to human dimensions. This also proves the importance of ergonomic and efficient HRI. The research in [3] extended this idea including factors like trust in automation, situational awareness, expertise, and expectations. A new user experience framework is formed for industrial robots. The results published in [3] prove that significant improvement in task execution may be achieved and the new system is more usable for operators with less experience with robotics. According to [4] a new approach for industrial robot user interfaces is necessary due to the fact that small and medium sized enterprises are more interested in automation. The increasing number of robot applications in small volume production requires new techniques to ease the usage of these sophisticated systems.

A new kind of robotics is now evolving from the experience of its ancestor, "cobotics", which has a high potential in the industry where the coexistence and cooperation of a robot and the operator is necessary. The world "cobot" is the contraction of cooperative robot what by definition needs to be safe. The aspects of this safety can be found in the following standards [5] [6] [7].

The usage of this kind of cobots generates new unexpected situations in the factories. A factory shop floor without fences where the operator can walk freely between the working stations with robots during operation can cause situations that the operator, "socialized" with robot cells with fences, can feel frightening. This is why an effective and ergonomic communication is crucial in a modern factory shop floor and the fields dealing with Human-Robot Interactions and Human-Robot Interfaces are getting more and more importance.

This paper's structure is as follows. Section II presents the investigated problem. In Section III the design of the LED strip is discussed both from hardware and software side. Section IV deals with the possible experimental testing of the discussed device to optimize its features and some potential applications are proposed. Section V sums up the investigation.

II. Problem Statement

The use of visual indicators on robots in mobile robotics and social robotics is a commonly used method for communicating the inner state. The research in [8] investigates the visual information notifications using standardized icons on the robot. The information mainly focused on the safety and the failures (safe, dangerous, OK, help, off). The usage of this kind of communication channel allows the robot to communicate its notifications not only for the operator but the bystanders, too. Any kind of additional mediating artifact is not needed. The disadvantage of visual notifications is that it is only effective when people are looking at the robot or they are aware of it [9]. This kind of disadvantage in cooperative situations is not significant, by the opinion of the authors, because of the constant expectation of the awareness of the robot from the operator. However, with operators performing multiple tasks the problem discussed above may occur. The focus of this research is to communicate the aspects of the robot posture beforehand as an imitation of the body language of a coworker working on the same task. One of the main contributions is this kind of new usage of visual indicators.

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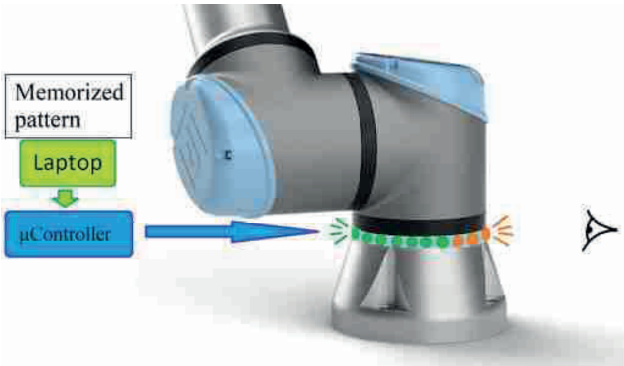

Fig. 1. Block diagram of the concept

Planning answers according to emotions and reacting to them symbolically and clearly is also an important part of the flexible and effective work between human and robots, which is one of the aims in the Industry 4.0. The equality of human and robot as working partners, for example in assisted shop-floor tasks, can be realized if the sensorics and the software with the human factor are harmonizable and able to extend the punctuality of the reaction time, behaving rather a human than a robot with predefined protocol, considering unexpected motions or reactions, while the freedom of the human worker is ensured, as it is mentioned and described in [10]. The concept of our hardware illustrated in Fig. 1 is a microcontroller controlled LED strip designed to "play back" patterns generated by a Python code based on a previously played robot program on the UR3e. The hardware is placed at the base of the robot that the operator is working with. This kind of visual communication can hopefully reduce the mental stress and increase the trust in the operator. For obtaining better results in such improvements further investigations with various lighting patterns and colors are necessary.

III. LED Strip

A. Hardware

The hardware – concerning the physical structure – is independent from the robot. It consists of a WS2812B RGB LED strip (with 24 LED controller units) and an Arduino UNO unit. The strip has three inputs: GND, DATA and VCC(5V). The DATA PIN is connected to a Digital PIN of the Arduino. A USB-cable ensures the connection between the computer and the main part of the hardware, the control unit.

The whole physical unit is placed at the robot's base and – with the exception of the RGB LED strip – covered with a 3D-printed case that protects the hardware from external impact. The LEDs take place in a special ring unit, consisted of three pieces, each of them is easy to open and close. There is a socket in the third ring unit, which collects the wires of the pins to ensure the correct connectivity. The path of the robot arm does not influence the punctuality of the sign. The sight is always clear for the human, so the preparations can be properly done for the right answer. The brightness and the combination of the colors also help us sense the light in time. We also set the width of the color of the position in such a way, that it can be seen in the operators blind spot. The hardware's geometrical model and the real hardware are illustrated in Fig. 2.

B. Software

The correct functioning of the whole system depends on two programs. One is uploaded to the Arduino UNO, which controls the color settings of each LED on the LED strip based on the received data from the computer. In this case the Serial Communication is fast enough to execute and react the changes in the potential investigated situations. Naturally, the syntax of the communication is defined by the authors. The data from the computer is passed to the microcontroller as a list with 25 elements. The passed data is divided into three parts. One is a list of length 24, which encodes the 24 LEDs' color, the last element of the list is the controller element. At the beginning of each list a special character (now *'A'*) shows the beginning of each command in byte format during the serial communication. The other software ensures the communication between the UR3e Robot (WiFi-Communication) and the Arduino UNO (USB-Serial Communication). This can be named as the main interface program. It was written in Python using special built in modules and functions.

A class was defined as the core of the program calculating the data to be provided to the microcontroller. As the scenarios for the proof of the concept enables to have a fixed program on the robot, the positions of the robot can be logged and preprocessed before the tests. The UR robot's logfile contains lists of 7 elements, each one in the following format:

$$[timestamp; x; y; z; rx; ry; rz] \tag{1}$$

where $timestamp$ is the robot's timestamp added to the data, x, y, z are the TCP's coordinates from the robot base coordinate system, rx, ry, rz are the TCP's rotations based on the same coordinate system. The preprocessing of the logfile consists of 3 steps. First, the rotational part of the lists is left and from the timestamps an average of the differences (dT) is calculated. (This is usually around $24ms$.) The result contains the timestamp from the start of the program in milliseconds and the coordinates of the Tool Center Point (TCP). After this, the polar coordinates (angles, distances, and z coordinates) are calculated from the Cartesian coordinates in such a way that the x axis of the robot base coordinate system is the reference. The form of the result is represented in Eq. (2).

$$polar = [\phi, r, z], \tag{2}$$

where ϕ is the polar angle, calculated by atan2 function, r is the L_2 distance from the origin projected to the $x - y$ plane at the robot's base and z is the TCP's z coordinate. This transformation of the 3D coordinates into 2D space section IDs is depicted in Fig. 3.

Fig. 2. The LED Strip in CAD model (left) and the parts in real life (right)

The IDs of the positions correlating to the section of the circle are calculated from the angles covered by a LED with the same ID using a floor-division of the angles.

$$ID = \left\lfloor \frac{\phi}{LED\_num} \right\rfloor + 1, \quad (3)$$

where ID is the ID of the corresponding section (or LED) of the space around the robot, ϕ is the polar angle calculated previously, LED_num is the number of the LEDs (or sections of space). The result of the division is incremented by 1 in order to fit to the communication structure.

The last step of the preprocessing is to determine the amounts of time the robot is staying in each sector. This is done by approximating the speed of the robot by simply counting the number of elements in each ID group (see Alg. 1).

The vectors for the LED strip are calculated based on the functional modes described in the next subsection. After generating the vectors another function sends them with the proper timing to the LED strip. The function requires a string with N (number of sections) length decoding the predefined colors. Finally, the string is formatted in such a way that the microcontroller understands the command and the command is sent to it. With this method it is possible to process the motion of a robot via the log file and on the next run the calculated gestures are played back which is suitable to such experiments with the color and flashing patterns.

Algorithm 1: Approximation of the “speed_vector”

```
Result: Vectors containing: ID, number of elements in
        the group, time approx.
x := first ID;
speed_vector := [];
n := 0;
for all IDs do
    if same ID then
        increment n;
    else
        append speed_vector with [ID, n, n · dT];
        x := next ID;
        n := 0;
    end
end
```

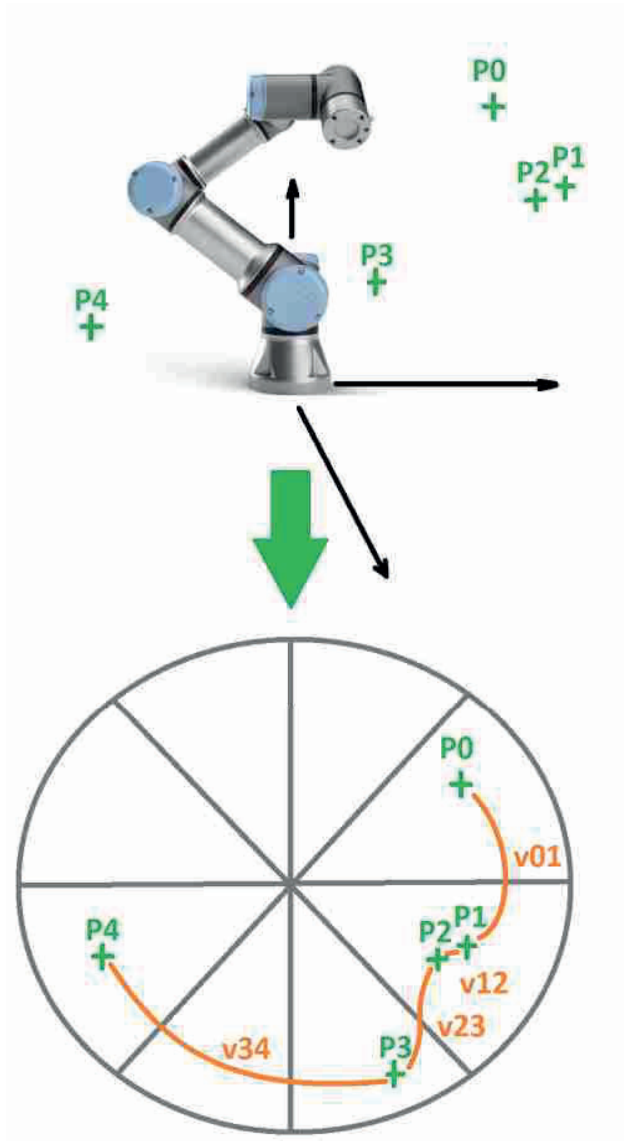

Fig. 3. Visualization of the concept of the TCP log to 2D surface speed conversion

C. Functional Modes of the Strip

To make sure that the operator receives the right intention of the robot in time, two basic concepts were worked out. The first idea was that the width of the indicator light changes according to the movement speed of the robot arm (Fig. 4, up). The second idea is to change the indication light’s color (Fig. 4, down).

Figure 4 illustrates us a partition of the LED strip (11 cells) during each method. The cells in the figure are representing the

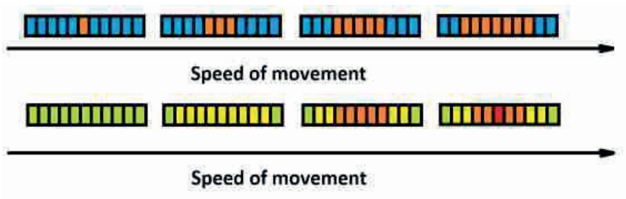

Fig. 4. Concept of the two kinds of functional mode. Up: Spatial based concept; Down: Color based concept

LEDs. The central LED is always facing to the same direction as the robot. From left to right the intended speed is increasing.

The first concept has the advantage, that the operator gets information about the speed by the width and the operator does not have to learn the meaning behind an exact color. The position color is constant as well as the basic color. This method can be referred to as spatial indication. This kind of concept alerts the operator of the movement as early as fast the movement is letting the operator to have more time to react. The concept's diagram is depicted on the upper side in Fig. 4 and the algorithm can be seen in Alg. 2.

Algorithm 2: Color string generation in spatial mode

Result: String containing the color code to all of the LEDs

Calculate $speed$ based on the $speed\_vector$ and $polar$;
Based on $speed$ select one of the ranges;
Assign same color to all the selected LED IDs symmetrically from the centered LED based on the range;

The second concept, where constant amount of indicating LEDs is used, varies the color depending on the movement speed of the robot arm (see Alg. 3). Unfortunately, this concept has more variables to investigate.

Algorithm 3: Color string generation in color mode

Result: String containing the color code to all of the LEDs

Set the width of the sign;
Calculate $speed$ based on the $speed\_vector$ and $polar$;
Based on $speed$ select one of the ranges;
Assign different colors symmetrically from the centered LED based on the range;

For an ergonomic and effective way of using this concept the near to optimal values need to be found of the following parameters:

- Angle of the indication. (Function determining the amount of LEDs for a gesture based on the movement speed.)
- Time between the indication and the real movement. (Function determining the timing of the visual signal based on the movement speed or a predefined value.)
- The palette of the colors for the different movement speeds. (Function determining the color of each LED based on the movement speed.)
- The resolution of the indication in terms of colors. (How much colors are needed to effectively communicate a movement speed.)

IV. Possible Experimental Testing and Other Applications

A. Possible Experimental Testing

The experimental testing will be crucial in validation of the idea. The expected result is that this kind of usage of the LED strip is able to lower the mental stress during the cooperation with robots via a more ergonomic communication. The types of tests are based on the interaction levels between the human and the robot explained in [11].

The first phase of the experimental tests is to measure the baseline of a group of volunteers to ensure the possibility of comparison. In this phase multiple type of measurements can and needs to be done such as the follows:

- The volunteer is only observing the movement of the robot. The lowest level of interaction. (Observation)
- The volunteer is working on a process while the robot moves. Higher level of interaction. (Shared workspace without shared task)
- The volunteer has physical contact with the robot (handing over situation). Highest level of interaction. (Shared workspace shared task / handing over)

In the first phase the LED strip is not included in the layout of the measurement. The second phase is the experimental testing of the effect of the LED strip on the mental stress, thus the LED strip is applied in this phase. All the types mentioned above are tested. The simplified layout of the measurements is illustrated in Fig. 5.

B. Possible Other Application of the LED Strip

In this section we would like to mention some other ideas of the possible uses of such device which we would like to investigate. In human cognition the awareness of other individuals is essential in social contacts (working together is also included in this idea). However, for a robot it is harder to effectively indicate this kind of awareness. A detecting framework with this kind of device could not only make a safer workspace in terms of physical damage but also in terms of mental stress. This can result in a closer to ergonomic workflow. Also with this kind of solution there is the possibility to avoid violations made involuntarily by the operator.

The idea is presented in Fig. 6, where on the left side an operator is working with the robot on a task while another person, who is not involved in the task, is approaching. The four possible stages are shown on the right, where the person is far (the robot's signal is green above the person's sign), then closer (yellow sing towards the person) and closer (orange) and when enters his restricted zone (red). The colors as mentioned earlier are target of a further research only the principle is important to see here.

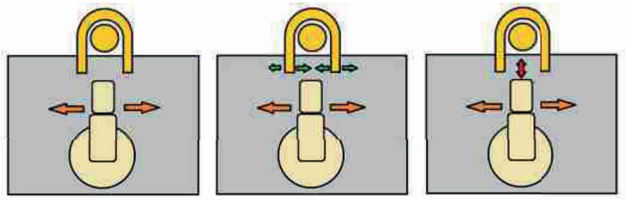

Fig. 5. Test layouts. Left: Observation; Middle: Shared workspace; Right: Shared task

For an ethologically inspired robot or a robot working in the fields of social robotics, this kind of device could be used or substituted on the robot's parts combined with other hardware in order to ensure a comfortable and safe process during the communication and the work. For example, a robot system consisting of various sensors and this device supported by AI based programs could mimic happiness when seeing a familiar individual and also warn a non-familiar individual to keep the distance.

Another potential usage here is in the field of autonomous vehicles. This kind of usage is very similar to the previously discussed one except that here the target is mainly to provide the vulnerable members of the traffic, such as pedestrians or cyclists, with the information of awareness. This can replace the eye to eye contact searching in a human with human situation.

V. Conclusions

In this paper a new way to use visual signals in human-robot interactions focusing mainly on the industrial robotics was proposed. The proposed idea can potentially result in a closer to ergonomic communication for situations described in this paper. The device is also usable in social robotics in different ways and in the communication systems of autonomous vehicles. The device was built and tested for functionality. To reveal principles to an ergonomic communication, huge amounts of tests needs to be done. Also the development of this device will be the target so in further works the experimental scenarios can step to the next, non static program, stage.

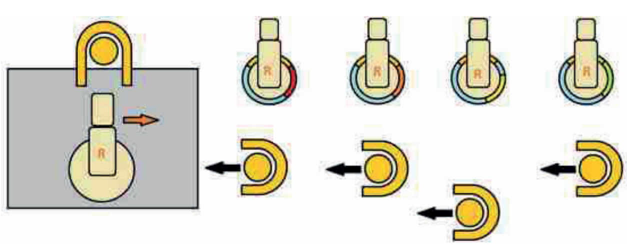

Fig. 6. LED strip indication change during the approach of an individual

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