Application of Mindstorms sensors in monitoring the fruit ripening process

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Abstract: In the present study, investigations were conducted to analyse the possibility of using the Lego Mindstorms light and color sensors in agriculture. The appropriate design was made which consisting of these sensors and control units that provided the information on measured values. The changes in color of tomato fruit (Lycopersicon esculentum Mill.) during maturation process were registered by using the appropriate color and light sensors with the analysis of the possibility of monitoring fruit ripening process and registration of any pathological changes of color. The values measured by sensors are presented in a graphical form, providing an analogy between the results given by Lego Mindstorms color sensor and Lego Mindstorms light sensor. The reliability of sensor readings was analysed by consideration of width of range of the results, from the beginning to the end of the maturation process and comparation with results of the other studies.

Keywords: agriculture, color sensor, fruit ripening, light sensor, Mindstorms

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1 Introduction

Agribot or agricultural robot is a robot that performs certain tasks in agriculture. In recent years, an increasing number of studies have been done aiming at examining the possibility of using the robots that can perform various tasks in crops, greenhouses, orchards and their potential to replace large and bulky machines. Wireless sensors and computer-programmed robots are the perfect combination to realize the above possibilities (Oljača V.M., 2008). Some literature sources mentioned several reasons for the inclusion of robots in agriculture, and some of them are: lower production costs compared with larger machines, saving time for work, increasing the protection level of people at work, obtaining higher quality products (Hannan and Burks, 2004; Kondo et al., 2005; Have et al., 2005). Several autonomous prototypes have been described for orchards and horticultural crops, such as robots for control of ripening and picking of oranges (Hannan and Burks, 2004), strawberries (Kondo et al., 2005) and tomatoes (Chi and Ling, 2004), but also self-propelled robot for monitoring of humidity, temperature, amount of minerals in the soil, as well as the robot for control of state of plants, their height and color (Mandsen and Jakobsen, 2001). Sensors are what enabled robot to perform the tasks in farming. Color sensor detects different colors in agriculture, and until now it was used for registering the changes of color on the fruit and differentiation of weeds. Pressure (touch) sensors are used to control fruit ripening in the orchards in the experimental conditions. Color CCD camera is very efficient in color change measurement, according to which registers the stages of ripening of plant fruits with great precision. Sensors measure the degree of fruit color and based on that determine the maturity and the time of picking. The mechanical design of the robot is also important when creating an agribot. The most commonly

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used form in experimental studies is kinematic robot arm that has three joints which allowed movements in directions of x, y and z axis in the working field.

Robots with legs are able to move. They are adapted for movement in the sand and soil, so they are also used in agronomically-mechatronics experiments. Robot – vehicle, that moves using wheels, is a frequently used model of robot for research on farms. Yaghoubi et al. (2013) made a brief review of the research on technologies in agricultural vehicles over the past two decades, concluding that the potential benefits of automated agricultural vehicles include increased productivity, application accuracy and operation safety.

Zhang et al. (2014) in their research used an unmanned aerial vehicle equipped with both an optical and infrared camera in order to monitor fertilizer trials, conduct crop scouting and map field tile drainage by using optical and near-infrared imagery.

Seelye et al. (2011) investigated the possibility of using color sensors for monitoring plant growth, and they also made an analysis of calibration technique for a RGB sensor and compare it with a high end spectrophotometer. In addiction, they compared information about plant color provided by color sensor and by camera through a software to determine the color of the pixels. They concluded that the image captured by a camera sometimes could provide false color readings, because plant leaves can overlap creating the shadows, while color sensor that uses its own light source to illuminate the sample surface which eliminates any potential shadowing.

Analyzing the quality of fruits in six ripening stages at a sample of 270 bananas, Rajkumar et al. (2015) concluded that zNose flavour detection data, as a non-destructive measurement method, can be use for prediction of quality parameters of fruits in different ripening stages.

Beside other environmental variables, Aziz et al. (2009) analysed the possibility of applying a remote temperature monitoring system using wireless sensor and Short Message Service (SMS) technology in order to measure the level of temperature and enable the alert of farmers regarding the temperature changes in the greenhouse, so that the early precaution steps can be taken, increasing the fruits and vegetables productivity.

In order to measure real-time crop conditions, Lan et al. (2009) developed a ground-based integrated sensor and instrumentation system which included crop height sensor, crop canopy analyzer for leaf area index, NDVI sensor, multispectral camera, and hyperspectroradiometer, with the aim of realizing multi-source information acquisition and management in the field.

Several studies show a positive correlation between the color of tomatoes and ripening stages, but this relation is not fully understood (Hertog et al., 2007; De Katelaere et al., 2004; Batu, 2004; Tijskens and Evelo, 1993; Thai and Shewfelt, 1991). Some studies are referred to the possibility of applying color and light sensors to monitor ripening of tomatoes, which would enable a better quality of fruit and reduced mistakes in picking tomatoes (Baltazar et al., 2008). Due to drastic changes in color in the final stages of maturation process, tomato was chosen as the subject of this paper, and the main aim of this study is to examine the possibility of applying the Lego Mindstorms light and color sensors, as one of an overriding and cheapest sensors, in monitoring the ripening of tomatoes. While the other similar studies are mainly oriented to registering the color of tomato fruit, the tendency of this study was to measure both color of fruit and intensity of light reflected from its surface, and to find an analogy between the obtained results.

2 Materials and methods

2.1 Equipment description and operation

A static robot with fixed base, Lego Mindstorms NXT and EV3 units and two sensors for color and one for light, was designed during this research. NXT control unit is an intelligent, programmable unit of Mindstorms robots. It contains the connections used to connect servo motor and sensor. The upper side of the control unit contains a

LCD display with 100x64 pixels. It has a speaker to reproduce the audio files. EV3 unit allows you to connect and manage up to eight different components, with four input ports for connection of sensors and four output ports to manage the servo motors, as well as 16 MB of memory. Six AA batteries (1.5 V each) or Mindstorms Li-Ion rechargeable battery with capacity of 2100 mAh could be used to power programmable control unit, as well as all other components of the robot.

In addition to programmable control units called “bricks”, appropriate sensors (color, light, ultrasonic, gyroscopic, sound, touch etc.), motors and connectors for their linkage, Lego Mindstorms package contains the plastic parts of various shapes suitable for joining together and forming different design solutions. In order to monitor changes in the color of tomato fruit in this research, robot, shown in Figure 1, was formed by mutual combination of individual parts of the Lego Mindstorms package. Robot was consisted of: NXT brick, EV3 brick, NXT light sensor, NXT color sensor, EV3 color sensor and static design with seat into which the fruit of tomato could be positioned.

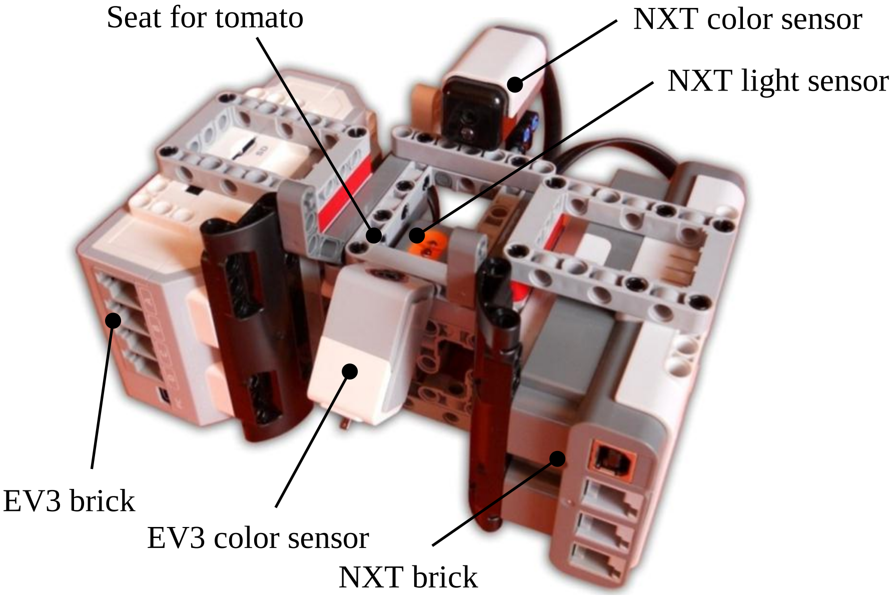
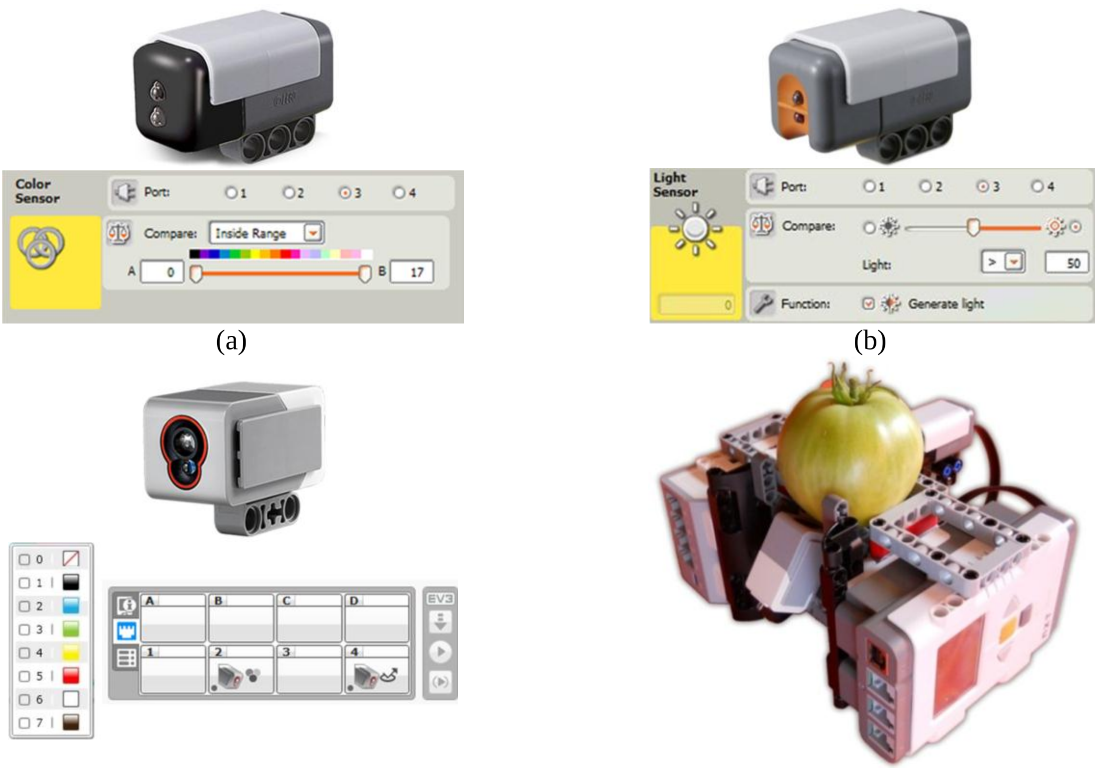


Figure 1 The look of robot for recognizing the changes in color and intensity of the reflected light of tomato fruit

Sensors for color and light were directed to the fruit of tomato, being able to recognize the color changes of the fruit and the changes in the intensity of light reflected from it. The seat is made with the aim of ensuring appropriate distances between the fruit and the sensors during measurements, because the distance affects the reading values. The object should not be positioned too close to the light sensor (lean on it), nor too spaced from it. Guidelines suggest setting the light sensor about 5 to 8 mm above the surface of object and color sensor about 8 to 16 mm above it (Mastering the Lego Robot, 2012; Lego Mindstorms Education, 2013). In the specific case, a fruit was positioned at a distance of about 5 mm from the light sensor and 8 mm from the color sensor. The structure is designed so that the sensors were placed at the appropriate sliders, allowing them to move from side to side in order to adjust their distance from the measurement surface, depending on the tomato size.

Figure 2 shows the Mindstorms sensors used in this study. NXT color sensor measures 18 shades of color, and its circumference of measurements is shown in Figure 2(a). NXT light sensor (Figure 2(b)) emits a light beam and measures the intensity of light reflected from the surface. It has a scale from 0 to 100, where 0 corresponds to totally dark, a 100 to totally light case. EV3 color sensor (Figure 2(c)) has the ability to measure the color of object, reflected light and ambient light. Unlike the NXT sensors that give information about the integer values of the intensity of reflected light, EV3 sensor and its corresponding software provide a numeric value rounded to two decimal places. EV3 sensor detects the eight colors: transparent, black, blue, green, yellow, red, white and brown. The aforementioned sensors were used to monitor the ripening process of Sort *Lycopersicon esculentum Mill.* (tomato) fruit – Figure 2(d).



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

Figure 2 Mindstorms sensors (a) NXT color sensor, (b) NXT light sensor and (c) EV3 color sensor used for (d) monitoring of the tomato fruit ripening process

2.2 Calibration of the system

Lego Mindstorms NXT and EV3 bricks were used to manage the system. The above mentioned microcontrollers come with the NXT-G and EV3 programming softwares, or optionally LabVIEW for Lego Mindstorms, although the programming can also be done in some programming languages like RobotC. NXT brick could be connected to four Mindstorms sensors and three Mindstorms engines using 6-position modular connectors, while EV3 brick could be connected to four Mindstorms sensors and four Mindstorms engines.

In order to transfer the necessary programs, a connection between bricks and computer can be achieved via USB or Bluetooth connection. Mindstorms programming software includes built-in program designed for calibration of the light sensor. After transferring the program on brick and its launch, it is necessary to place the light sensor above black base and press the "Enter" button on the brick, and then over a white background and press the same button again. The light sensor is calibrated after that. Given the fact that bricks and sensors are active all the time during the monitoring of process of fruit maturation, it is not necessary to take any additional calibration or adjustment of the system, nor perform calibration of the other light sensors connected to the same brick, but only one. EV3 color sensor is necessary to calibrate in the same way only if it is used to determine the intensity of reflected light (Lego Mindstorms Education, 2013).

2.3 Data analysis procedure

Ambient light may affect the light sensor readings, although shading the light sensor will minimize the effects of ambient light on the light sensor readings (Mastering the Lego Robot, 2012). To determine the influence of ambient light on the sensor readings, fixed-colored ball was kept it in the robot design for 24 h. Once every four hours reading the value on the color and intensity of light reflected from the object surface was done. By observing the object of constant color in different times of the day, we found that the values measured by a light sensor may vary in decimals, while the values measured by a color sensor stay unchangeable. This means that changes in ambient light in the specific case had very little influence on sensor readings. The reason for this is the fact that the design was static and that the sensors, i.e. the measurement surfaces, were sheltered by the tomato fruit from the direct influence of other light sources.

Baltazar et al. (2008) performed color measurements over a period of 30 d using a Minolta CR 300 colorimeter in order to notice changes in the color of stored tomatoes. The equipment they've used provided an estimate of values that indicated the slight color changes by calculating chroma orhue angle. Analogous to the above-mentioned research, we put green (immature) tomato fruit in the previously prepared design and held it in the same position and at the same location over a period of 10 d in a closed room at a temperature of about 20 ℃. Unlike Baltazar et al. who followed the changes in color of the fruit, changes in both color and intensity of the reflected light were analyzed in this research by using Lego Mindstorms color and light sensors. Reading of values on the color and intensity of the reflected light was done twice a day. As the fruit was maturating in the indicated period, it color was being changed, so the values registered by sensors were different. Each measured value was recorded, and the trend of the changes in a graphical form for the indicated time period was formed.

3 Results and discussion

In this study possibilities of application of color and light Mindstorms sensors in monitoring the fruit ripening process were analysed on the example of tomato fruit (*Lycopersicon esculentum Mill.*). *Lycopersicon esculentum Mill.* (family Solanaceae) is a perennial plant that reaches a size of up to 3 m (Warnock S.J., 1991). The fruit of this kind is red and usually round in shape and can reach a size of up to 10 cm in diameter (Suganuma et al., 2002). The time between fertilization and forming of red fruit is from 7 to 9 weeks (Atherton and Rudich, 1986).

Continuous observation of the values that were read by sensors enables monitoring of the maturation process of the tomato fruit (*Lycopersicon esculentum Mill.*). Figure 3 shows the values registered by the Lego Mindstorms light sensor.

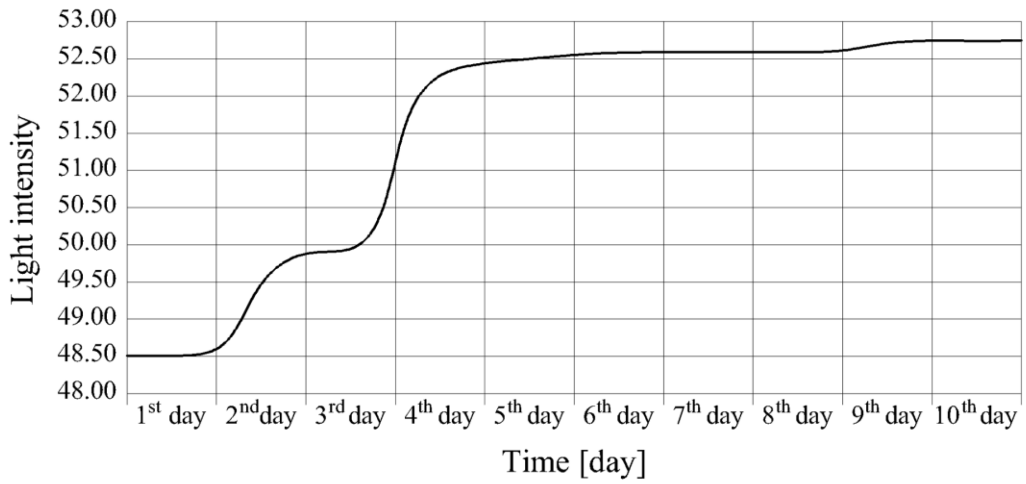


Figure 3 Diagram: reflected light intensity – time

Figure 4 shows the values registered by the Lego Mindstorms color sensor.

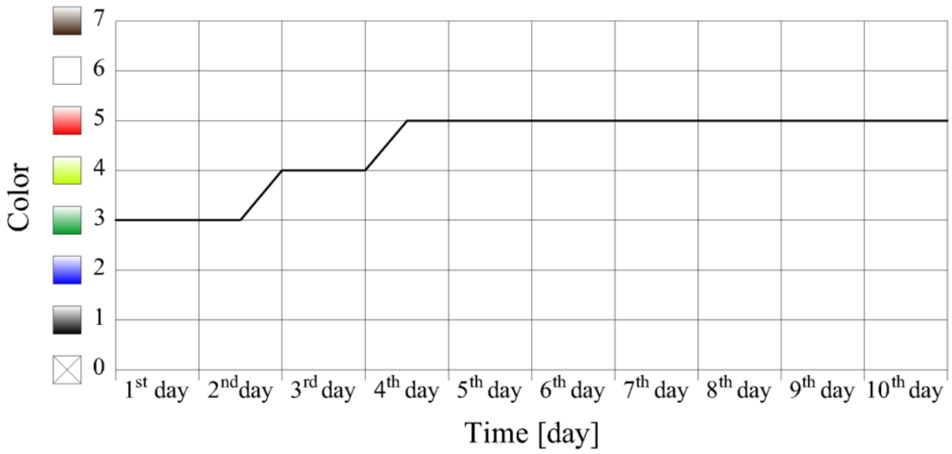


Figure 4 Diagram: tomato color – time

Based on the values set forth in the preceding figures, it can be seen that the largest changes in color occurs between the second and fourth day, and it is a period in which tomato fruit (*Lycopersicon esculentum Mill.*) matures. Variations in reflected light after four days are negligible, while the measurement of color sensor remains unchangeable.

The light reflected from the surface of completely green tomato is 48.51, of pink tomato around 49.88 and of the completely red tomato 52.75. It has been noted that the intensity of the reflected light changes in a range of 48 to 53, on a scale from 0 to 100. The range interval is small if only the integer values are read (as in the case of software NXT). However, since EV3 software identifies values rounded to two decimal places, this interval is large enough to be able to use the light sensor to monitor the process of maturation of the fruit.

Color sensor measurements indicate that the color difference between immature and mature fruit is visible for the sensor. However, the pink color of tomato is recognized as yellow by sensor. The reason for this is the fact that feedback of EV3 sensor is limited to only seven colors, which does not provide space for understanding the nuances of individual colors, but nevertheless allows him to give information about the ripening of the fruit.

4 Conclusions

The analysis of changes in the color of tomato fruit and light reflected from its surface indicates the possibility of applying NXT and EV3 Mindstorms color sensor and light sensor for the registering of changes in colors of fruit plants in farming and monitoring of their maturation, by providing the reliable results, which do not differ to a greater extent to the literature data such as Baltazar et al. (2008) and Xuming C. (2015).

As the NXT and EV3 bricks are programmable, the process of monitoring the maturation of the fruit could be improved, i.e. after achieving the proper color/reflected light intensity of fruit, programmable brick can beep in order to signalize user that fruit is ripe (or provide a signal in some other form) and activate motors that will separate the fruit from the tree.

Although the range of colors that can be registered is relatively small, it was proved that it can be used for the purpose of monitoring the process of maturation of the fruit. Depending on the intended use of the color sensor, i.e., type of fruit for which maturation process need to be followed, it is preferable to use these sensors in RGB mode, providing information about color as a combination (mixture) of red, green and blue, which enables the detection of any hue of color. Ambient light changes do not affect the color sensor readings, but affect a little bit the light sensor readings.

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