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Introducing i-puck: An Educational Mobile Robot

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***Abstract*—The employment of mobile robots in educating undergraduate and graduate students are shown to be an effective complementary tool to traditional methods. In fact, students will effectively get involved in theories which they learn in related courses of Artificial Intelligence and Robotics area. Currently, the available mobile robots are mostly capable of handling specific tasks such as localization, mapping, and path planning. However, most of them are not affordable and/or not widely available to all. In this paper, i-puck, an affordable mobile robot inspired from e-puck, is introduced. i-puck consists of essential modules needed for teaching AI and robotics. In this paper, we explain the use of i-puck in teaching robot localization and mapping.**

Keywords—complementary educational tool; mobile robot; i-puck;

I. Introduction

It is essential to get undergraduate and graduate students motivated and involved in academic courses [1]. This would give students the opportunity to learn and understand theoretical lessons of courses in more depth [1], [2]. Hence, curriculums usually offer experimental assignments and projects to reach this goal. Fortunately, there are number of tools and platforms available to design and accomplish these tasks. Due to the aggregation of many engineering aspects in mobile robots, e.g. mechanics, control, electronics, and computer, this type of robots provide multiple frameworks for academic experiments and research areas [3]. As a result, mobile robots are widely used in universities, in Computer Science, Computer and Electrical engineering, Artificial Intelligence and Mechanical engineering [3], [4], for research and education.

There are many mobile robots available for education. The sensor integration of these robots made them appropriate for educational tasks in Artificial Intelligence and Robotics area, such as localization, mapping, and path planning. In addition, the communication method of these robots with personal computers is usually managed by conventional interfaces, e.g. USB port, Bluetooth, or Wi-Fi. Therefore, students can program robots and test their implemented algorithms through the communication module of these robots. The specifications of some educational mobile robots will be discussed more in detail in the next section.

The majority of the available educational mobile robots are very expensive. This high price becomes more prevalent since universities have to purchase number of specific mobile robot in order to utilize them as complementary educational tools in laboratory-based class sessions. Thus, the robots are not available to a wide range of universities. As a result, a low cost and easy to use mobile robot, i.e. i-puck, has been introduced. i-puck can be used in many educational tasks related to Artificial Intelligence and Robotics area, especially those that are discussed in courses which include localization, mapping, path planning, and navigation. Fig. 1 shows an image of the robot alongside of its sketched model. What comes next is a brief review of mobile robots that are widely used in education.

II. Educational Mobile Robots

Using LEGO Mindstorms™ [5] in undergraduate Artificial Intelligence and Robotics courses as a complementary tool offers an interactive and effective learning environment [6]. Moreover, they are easy to use, and have open source software [7]. Number of sensors such as gyroscope, compass, accelerometer, and angle sensors have been included in the LEGO Mindstorms™ set. Also, the communication with robot is made through either Bluetooth or USB port. It should be mentioned that the flexibility in the design of mechanical systems, provided by LEGO Mindstorms™, offers a very good environment to ignite the creativity of the students. However, its processing module and sensors are limited which makes it not suitable for complex tasks.

Reshko et al. [8] designed and developed the Palm Pilot Robot Kit (PPRK) which is based on Acroname's BrainStem [9] controller and contains three infrared (IR) proximity sensors, and a handheld computer. The communication with the robot is available through USB port. The robot has been primarily designed for studies in robotics field. Hence, it is not appropriate for lab session experiments and testing.

AIBO [10], from Sony, is an open platform that was initially used in RoboCup competitions. Due to its embedded features, such

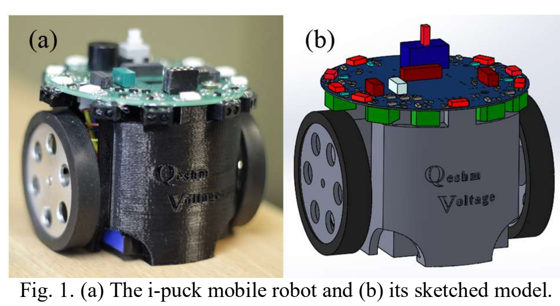

Fig. 1. (a) The i-puck mobile robot and (b) its sketched model.

as its movement capabilities and sensors, it has been used in different courses such as a particular course at Carnegie Mellon University in which the implementations of a wide variety of Artificial Intelligence topics is discussed using AIBO [11]. Many sensors such as touch sensors, camera, IR proximity, microphone, heat, accelerometer, and angular velocity are embedded in the robot. Unfortunately, this robot is fairly expensive and out of reach for typical students or even many colleges to use them in their courses. Furthermore, it is only suitable for topics related to 4 leg robots and cannot be used for mobile or biped robots.

Harlan et al. [12] believe that Khepera II robot from K-Team [13] provides the opportunity to practice robotics in a real world setting. Khepera II includes sensors like IR proximity and ambient light sensors. The communication with the robot is available through a standard serial port. In addition, predecessor of this robot, Khepera III and Khepera IV have been released. Khepera III comes with sensors such as IR proximity, ambient light sensors, Infrared ground proximity sensors, and ultrasonic. The communication is made by either standard serial port, USB port, Ethernet, or Wi-Fi. In comparison to Khepera III, Khepera IV has two additional sensors, accelerometer, and gyroscope. The communication in Khepera IV is available through USB port, Wi-Fi, or Bluetooth. The high price of this robot, makes it only suitable for schools with large funding. Furthermore, its size makes this robot hard to be used in small labs and needs large environment for conducting labs and experiments.

Moreover, Hemisson, also from K-Team [13], is equipped with number of sensors such as IR proximity, ambient light sensors, and IR ground proximity sensors. The communication with robot is available by only a standard serial port. Thereby, the communication method of this robot would not be ideal as an educational robot. In addition, the number of integrated sensors is not adequate enough to suite the robot in difficult tasks.

K-Team also offers K-Junior [13] which comes with an array of sensors such as IR proximity, IR receiver/emitter sensors, ambient light sensors, and Infrared ground proximity. In particular, the IR receiver/emitter sensors is suitable for studies related to multi-agent systems and collective behavior modeling. The communication of this robot is available by either USB port or Bluetooth. The size of the robot, make it almost inappropriate for desktop applications such as lab session experiments.

K-Team's Kilobot was designed for the purpose of swarm robotics studies. It has IR proximity, IR receiver/emitter, and ambient light sensors. The communication is available through either USB port, or the debug cable of Kilobot. The main feature of this robot that makes it a swarm robot is that it is capable of communicating with neighbors up to 7 cm. Also, its small size allows experiments with large number of these robots. However, these robots lack many features needed for experiments such as localization and mapping.

Another mobile robot from K-Team, named Koala V2.5 [13], has been primarily designed for outdoor applications, e.g. surveillance tasks. It comes with sensors such as ultrasonic, accelerometer, gyroscope, and magnetometer. The communication with robot will be made by USB port, standard serial port, or Ethernet. it is also equipped with a powerful computation power. The price of this robot is fairly high for conducting lab sessions with several students.

The Pioneer P3-DX robot [14] offers a platform where users can customize sensors and actuators. It also accepts different processors to cover multiple tasks. The communication is available only by Wi-Fi. Similar to many other robots, it is expensive such that it cannot be bought in numbers to conduct course-based labs. It is mainly suitable for research or courses with very few students.

Mondada et al. [3] proposed a desktop size robot, e-puck, that can be used in wide range of educational goals. It includes various sensors such as IR proximity, accelerometer, microphone, camera, IR receiver/emitter. The communication to the robot can be done wirelessly through Bluetooth or with RS232 cable. There are multiple extensions features that can be applied to the robot. Hence, e-puck is ideal for studying a wide range of engineering and scientific topics.

Table I briefly shows the approximation price of the aforementioned mobile robots alongside their main educational purposes.

Our experience shows that an ideal mobile robot for academic education should have number of essential factors. The most

TABLE I. THE PRICE AND MAIN USAGES OF MENTIONED MOBOLEROBOTS IN EDUCATION.

Mobile Robots	**Two Essential Factors in Educational Mobile Robots**	
	Price	***Usage in Education***
PPRK	300	Robotics, Localization, Mapping
LEGO Mindstorms™	350	Undergraduate Artificial Intelligence and Robotics
Hemisson	410	Localization, Mapping, Navigation
K-Junior V2	770	Localization, Mapping, Navigation, Multi-Agents System, Control, Collective Behavior
e-puck	870	Localization, Mapping, Navigation, Signal processing, Automatic control, Behavior-based robotics, Multi-agent systems, Path Planning
Kilobot	1320	Swarm Intelligence, Multi-Agents System
Khepera II	1750	Localization, Mapping, Navigation, Multi-Agents System, Control, Collective Behavior
Khepera III	2300	Localization, Mapping, Navigation, Multi-Agents System, Control, Collective Behavior
AIBO	2500	Human-Robot Interaction, Robocup, Control, Artificial Intelligence and Robotics
Khepera IV	3180	Localization, Mapping, Navigation, Multi-Agents System, Control, Collective Behavior
Pioneer P3-DX	4000	Mapping, teleoperation, localization, monitoring, reconnaissance, vision, manipulation, navigation, Multi-Agents System
Koala V2.5	12600	Tele-manipulation, Mapping, Path planning, navigation, Object recognition, Surveillance, Tour Guide

important factor would be robot's sensors. Obviously, more sensors integration will result in more applicability of a robot to wider educational tasks. In addition, the way that robots communicate with computers are also important. In fact, a user friendly interface that handles the connection and the programming of an educational robot is an ideal for such robots. As a result, researchers and students would focus on their tasks and bypass the difficulties involved in coding, simulating, and executing the algorithms. Besides, the accuracy and range of sensors plays a vital role in mobile robots. Finally, it is essential that, in contrast to satisfying all of above factors, the cost of these robots remain as lowest price as possible. Therefore, they can be available to many educational centers having different budgets.

According to Table 1 and our earlier discussions, most of the mentioned mobile robots has a fair number of sensors and their communications are commonly made through conventional methods. However, most of these mobile robots are too expensive to afford or offer limited capabilities like connection interfaces. But, among them, e-puck is a relatively low-cost mobile robot with various types of sensors and capabilities. Therefore, in this paper we introduce an educational mobile robot, i.e. i-puck, which has been inspired from e-puck. In comparison to e-puck, i-puck includes more accurate sensors for longer ranges. It also has more convenient communication method, by using WiFi, with personal computers. Finally, its predicted price will surely make this robot more affordable than e-puck.

III. THE I-PUCK MOBILE ROBOT

Fig. 1 (a) shows the final version of i-puck mobile robot. The robot is designed, developed, and produced at the Robotics, Artificial Intelligence, and Information Sciences institute, University of Tehran for Qeshm Voltage company. In the following, the specifications of i-puck are provided.

- Eight IR proximity sensors: the maximum range of these sensors are twenty centimeters. Similar to e-puck, they have 12-bits long accuracy. These sensors are shown as green boxes in Fig. 1 (b).
- Eight RGB LEDs: the RGB LEDs are provided to specify accomplishing particular tasks. These LEDs are shown as bright red boxes in Fig. 1 (b).
- Lithium-ion battery: the battery can support 2 operating hours and can be easily recharged through a micro-USB cable.
- Wi-Fi communication module: the connection between robot and computers can be made through this module.
- I/O extension: the extension is provided to support camera, ultrasonic, gyroscope, and LCD modules.
- An open source code for robot's microcontroller: the source code is available for everyone who desired to accomplish a particular task in the level of microcontroller programming.

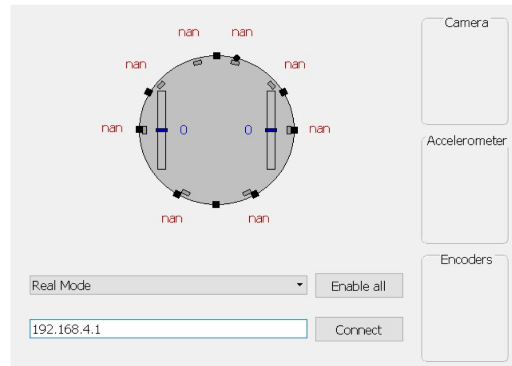

Fig. 2. The i-puck's connection GUI. The robot IP address is needed to make a connection.

A simulated version of i-puck has been designed in Webots [15]. Therefore, students and researchers can conveniently design, implement, and test their tasks in a simulation environment, where it is free of real-world complexities and difficulties. Also, by using the Webots software, the robot can be connected though a robot window (Fig. 2) which is designed specifically for the i-puck robot. Hence, different tasks can be tested in real-world settings too.

IV. ROBOT ARTCHITECTURE

As mentioned earlier, architecture of i-puck robot is very similar to e-puck robot except in two modules, robot's motor and its communication with personal computers. Fig. 3 shows the main parts of i-puck. What comes next is an illustration of these modules.

A. *Robot's DC Motor*

i-puck robot's motion is supplied by two DC motors. In comparison to stepper motors of e-puck, they are more available, have longer lifetime, have lower price, and offer a better speed control. Although utilizing them in i-puck robot was obviously more challenging than stepper motors, the existence of the mentioned advantages of a DC motor are essential in an educational mobile robot.

In addition, using shaft encoders in the robot's motor, has provided a closed-loop control. Therefore, possible related errors

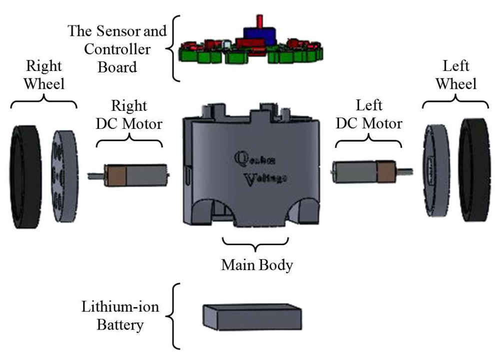

Fig. 3. The parts of i-puck robot.

can be recognized and resolved which is not possible if stepper motors are used.

B. Wi-Fi Communication Module

In Webots, each step of the simulation is based on duration of a time step. In other words, at each time step, a request packet is prepared by the Webots software and sent to the robot's microprocessor via the Wi-Fi module. The microprocessor receives the packet, interprets it, and run the request command. The microprocessor has been designed based on the ARM architecture [16] and the protocol of the commands is according to the USART protocol. After making all request commands on the robot, the ARM microprocessor prepares the corresponding response packet and sends it back to Webots again through the Wi-Fi module. This procedure will continue until the end of the simulation. Generally, the time step is set in terms of milliseconds (ms) and 32ms is considered as a default value.

The ARM microprocessor intercepts each request packet based on its content. Actually, each packet contains a flag and a value. The flag indicates a request command, for instance flag L is considered for setting an LED, and the second one shows its corresponding value, for example the color of the corresponding LED of the robot. Fig. 4 shows the communication process at each time step.

V. Using I-puck Robot in Education

Due to the sensors integration of i-puck and its specifications, several educational tasks can be accomplished using the robot. Also, the robot can be employed in several research areas. In the following, a brief description of the educational tasks and the way of tackling these tasks by utilizing i-puck robot have been illustrated.

A. Path Planning

The Path Planning task is to find a valid and secure path from arbitrary start and final points in a given map [17]. Multiple related algorithms, such as Bug Algorithms and Roadmap methods [17], can be easily implemented by using the robot's IR proximity sensors. Also, Path Planning in Dynamic Environments can be effectively done. This is because of the fact that the data can be transferred rapidly through the Wi-Fi module. Also, the speed of each wheel can be selected from a wider range in compare to e-puck. In detail, e-puck maximum speed is reported 15 cm/s, whereas i-puck maximum speed is 20 cm/s.

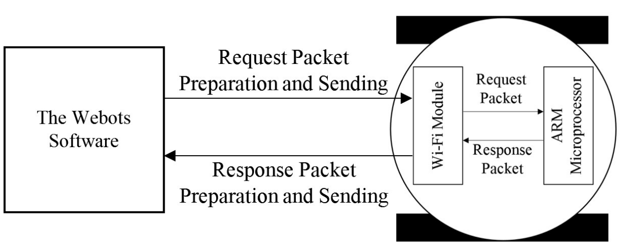

Fig. 4. The communication structure with Webots.

B. Localization

The localization task is to determine the position of a mobile robot in a given map [18]. The task can be achieved by using different approaches such as Particle Filters (PF) algorithm [18]. The IR proximity sensors of i-puck robot can be utilized in order to specify the distances of obstacles in different directions of the robot. Therefore, calculating the probability of every particle representing the correct location of the robot, would be easy. As discussed, the IR proximity sensors of the i-puck robot are 12-bit long, which makes them accurate enough for this task. It should be mentioned that similar lab has been designed, developed, and executed in the advanced robotics course, at the school of Electrical and Computer Engineering, University of Tehran (UT). In this course, the students learn how to develop the sensor model and motion model for a robot. Then they employ different localization methods, such as Extended Kalman Filter [19] or PF, in a room type environment (Fig. 5). The laboratory syllabus of this course will be discussed in detail in the next section.

C. Mapping

The Mapping task is to obtain the map of the environment where a mobile robot operates in it [18]. This task can be tackled by the Occupancy Grid Mapping algorithm [18]. Similarly, the IR proximity sensors of i-puck can be employed as robot's measurements in order to calculate the posterior probabilities of maps. Again, the accuracy and range of the sensors plays an important role in this task.

D. Simultaneous localization and mapping

As it can be inferred from the title, the Simultaneous Localization And Mapping (SLAM) is to accomplish the localization task in an unknown environment, hence the robot should also do the mapping task in parallel [18]. Likewise, the robot's measurements in this task can be the raw values from its IR proximity sensors.

E. Multi-agent systems

The communications between agents are critical in this field of study. The Wi-Fi module of i-puck provides a fast and trustworthy platform for the communication. In detail, one of the i-puck robots

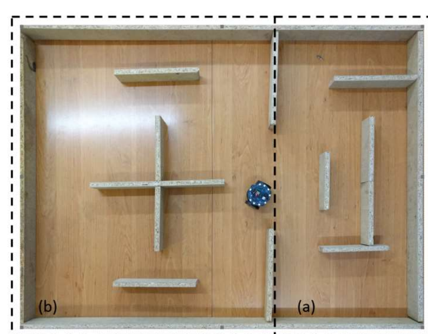

Fig. 5. The i-puck robot in a maze like environment. The maze consists of two sections, (a) easy section and (b) hard section.

can be exploited as a server, and the other i-puck robots connect to it as clients. Thereby, a peer-to-peer communication between arbitrary pair of robots can be established through the server. Also, the open source microcontroller of the robot let researchers to construct their desired multi-agent platform.

F. Other Educational Tasks

Similar to e-puck, the i-puck can also be used to design and practice simple Automatic Control Systems [3]. Also, since the path planning and localization tasks are possible, then the combination of those, i.e. navigation, is also applicable by using the robot. Moreover, the open source code of the robot's microcontroller alongside of a serial port allows researchers to modify or change the platform of the robot. Therefore, the robot can be utilized as a tool in embedded-system field of study.

VI. Advanced Robotics Laboratory Syllabus at UT

As mentioned earlier, as one of the main tasks, students are asked to solve localization problem of i-puck mobile robot in real-world settings. The task depends on two prerequisites, i.e. obtaining the sensor and motion models of the i-puck in use. In the following, the steps needed for accomplishing localization task by using an i-puck are discussed.

A. Obtaining Sensor Model

Students are asked to use IR proximity sensors of i-puck. In general, the sensor model of a proximity sensor is a combination of four probability density functions (PDF) [18]:

- Correct range of an obstacle with some errors (P_{hit})
- Correct range of a dynamic obstacle,

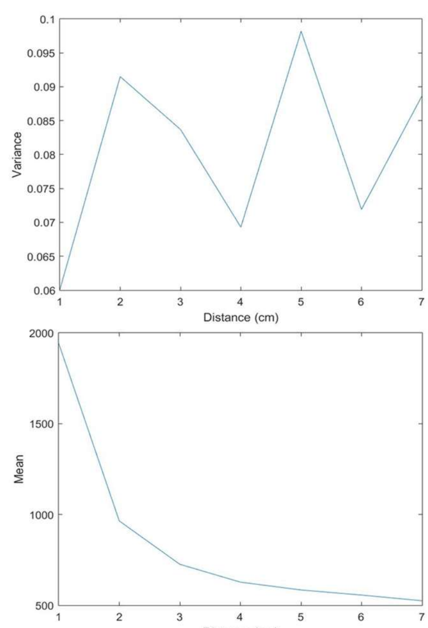

Fig. 6. The estimated means and variances of the first IR proximity sensor.

- Missing of an obstacle, and
- Random measurements.

Among these PDFs, only the first one is desired. In fact, there are no dynamic obstacles in the environment. In addition, since the IR proximity sensors are accurate enough, there will be no errors like missing obstacles or random measurements. Talking about a particular sensor, P_{hit} is assumed to have number of Gaussian distributions, each corresponds to a particular distance. Therefore, students need to obtain the mean and variance of each Gaussian distribution. The parameters can be estimated through adequate number of samples from each of the distributions. Fig. 6 shows a sample results of estimating means and variances of an IR proximity sensor.

B. Obtaining Motion Model

Possible errors in robot's motion are generally consist of the following failures [18]:

- Translation error in translation motion (α_1),
- Rotation error in translation motion (α_2),
- Translation error in rotation motion (α_3), and
- Rotation error in rotation motion (α_4).

Similarly, the PDF of each error is assumed to be Gaussian. Hence, estimating parameters of Gaussian probability distributions are desired. To do so, students are asked to arrange two experiments, i.e. translation and rotation motions, and measure the mentioned errors. Repeating each experiment for reasonably enough number of iterations, will result to obtain a sample collection for each error. Therefore, mean and variance of each error are computable. Table II shows our preliminary tests performed to obtain the mentioned parameters. After obtaining sensor and motion models of their i-pucks, students should solve the localization task for the robot in a real-world room type environment (Fig. 5) using Particle Filters algorithm.

VII. Discussion

Many educational tasks related to Artificial Intelligence and Robotics fields of study can be practiced using an i-puck mobile robot. For instance, the main theories in robot localization and mapping, that are usually discussed in Advanced Robotics course at the School of Electrical and Computer Engineering in the University of Tehran, can be practiced using i-puck. Specifically, Table III shows the syllabus of the Advanced Robotics course and

TABLE II. Obtained The Motion Model Parameters

Motion Model Errors	Gaussian PDF parameters	
	μ	σ^2
α_1	-0.019244	0.000734
α_2	-0.00014	0.0000000735
α_3	0.014448	0.000000660
α_4	0.000382	0.000000020264

TABLE III. THE APPLICABILITY OF I-PUCK IN TOPICS THAT EXIST IN SYLLABUS OF ADVANCED ROBOTICS COURSE, AT THE SCHOOL OF ECE, UNIVERSITY OF TEHRAN.

Syllabus of Advanced Robotics Course		Applicability of i-puck
Probabilistic Roadmap	Path Planning for a Point Robot	✓
	Configuration Space for a Robot	✓
	Probabilistic Roadmaps	✓
	Collision Checking and Distance Computation	✓
	Uncertainty in Path Planning	✓
Probabilistic Robotics	Kalman Filter Fundamentals	×
	Particle Filter Algorithm in Localization	✓
	Probabilistic Motion Models for Mobile Robots	✓
	Probabilistic Sensor Models for Mobile Robots	✓
	Extended Kalman Filter in Localization	✓
	Mapping with Known Poses	✓
	Simultaneous Localization and Mapping	✓

applicability of i-puck in each topic. According to Table III, using i-puck robot, as a complementary educational tool in this course, will help students to have a better understanding of almost all of the topics.

In addition, the I/O extension of the robot can add more capabilities to it. Therefore, it can be used in other educational topics and studies. For instance, adding a camera extension may yield a research field, namely image processing in mobile robots. Furthermore, the I/O extension can be used to gain more accurate measurements through data fusion of different sensors, e.g. combination of IR proximity and ultrasonic sensors. Moreover, an LCD can be attached to the robot by using this module. The LCD surely helps students to monitor the overall status of i-puck which is suitable for debugging and testing.

It is also worth to say that, the enhanced power supply of i-puck made the use of this robot more comfortable, since it can last long throughout a typical lab session.

VIII. CONCLUSION

In this paper, a new educational mobile robot, named i-puck, has been introduced. There exist many educational robots designed and implemented specifically for core theories in Artificial Intelligence and Robotics area, such as robot localization, mapping, and path planning. The majority of these robots are not affordable. However, i-puck offers an integration of several sensors, e.g. infrared (IR) proximity sensors, at reasonably low cost.

It is obvious that i-puck satisfies the basic requirements for an educational robot, i.e. having a wealth of sensors and proper communication and coding environment to make it usable in educational setups. Furthermore, it has good sensor accuracy and good sensor range which makes it suitable for several different educational tasks. Finally, it is almost the cheapest in the market which makes it affordable for educational tasks.

i-puck is equipped with eight IR proximity sensors. By using these sensors most of the essential educational topics and theories in Artificial Intelligence and Robotics can be practiced. In addition, the I/O extension module of the robot, allows adding more sensors such as ultrasonic, and camera. Plus, the robot's motion is governed by a DC motor. Finally, using the necessary sensors alongside of the use of a DC motor, keep the robot's price as low as possible. Furthermore, a Wi-Fi communication module has been integrated with the robot. So, the connection between robot and personal computers can be done more easily. The data transmission will be also quick enough to accomplish real-time tasks. Moreover, the range of the IR proximity sensors is twenty centimeters. Also, the accuracy of these sensors is 12-bits long. Thereby, they are surely precise enough to support robot in accomplishing aforementioned tasks.

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