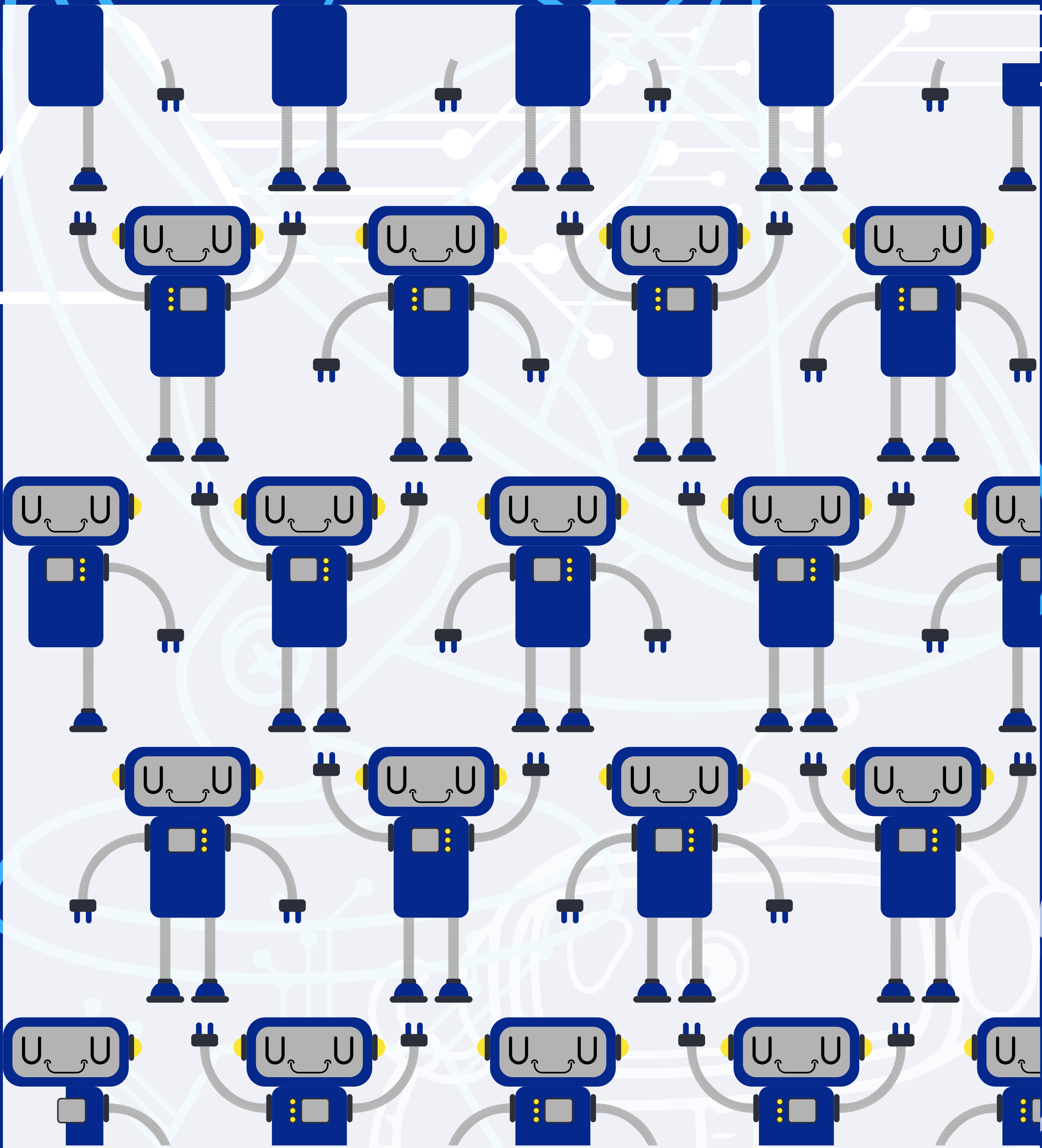

iWire Curriculum

An Initiative by Jai Gupta

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ABOUT THE PROJECT

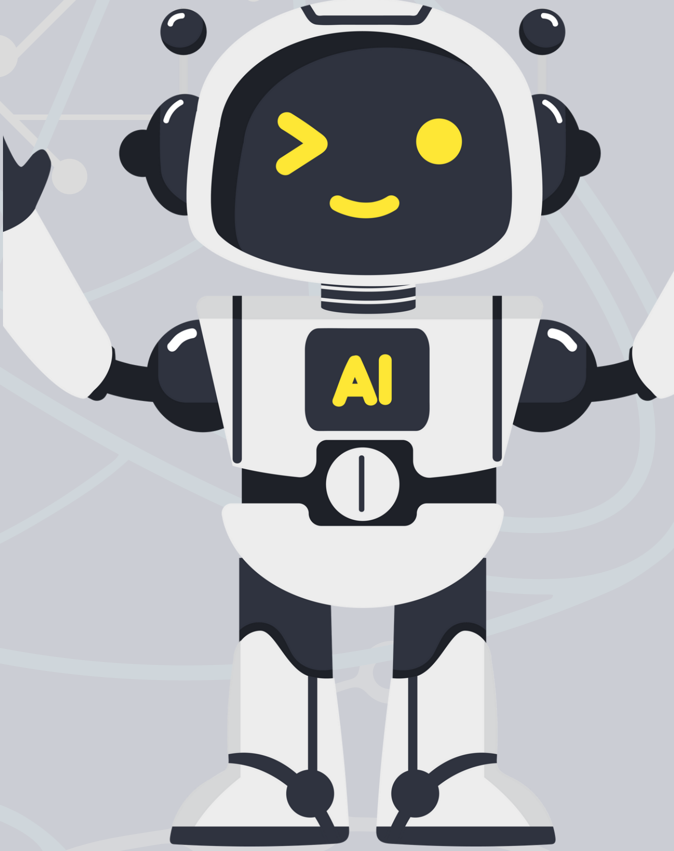
In India, in a study conducted by the Ministry of Education from the period 2012-22, results showed that Science was the most popular stream for students at the higher level, with roughly 42% of the students opting for the subject. With a larger vision to help spread science education to India's underserved and often overlooked student communities, the W.I.R.E.D (Wandering Into Robotics EDucation) was launched in July 2022 to ramp up access to an extensive education in robotics and related fields, and increase awareness about the benefits of an innovative STEM education in empowering students.

MESSAGE FROM THE AUTHOR

From a young age, I have always been fascinated by the inner workings of everyday products. Taking apart toy cars, remote controls, and even toy robots, understanding what makes a product 'whole' has always been of interest to me, perhaps forming the underpinnings of my ardent admiration for robotics. Moreover, upon learning about the benefits of robotics education, such as how the intricate problem-solving and critical thinking skills imbibed through engaging with the discipline can be fruitful in everyday life, I became immensely keen to hone not just my skills, but also those who may not have access to this on an everyday basis.

To that end, the iWire curriculum seeks to serve as a robust resource for our readers to enjoy the benefits of robotics, and firsthand experience the advantages of building your robot, one step at a time.

AN INTRODUCTION TO ROBOTICS PROJECTS



We know Robotics refers to one particular branch of science that uses engineering and computer science principles and is concerned with the conception, design, manufacture and operation of robots. Now, while we may think of robots as humanoid figures, with 2 sets of limbs, a face-like structure, and mechanical movements, in reality, robots come in many different shapes and sizes, even drastically different from what we could have imagined or conceptualized. For example, a disc-shaped floor vacuum would normally not fit into our schema of what a robot is, but it is one of the most popular forms of residential robots. This diversity in robots goes to show just how pervasive they are in our day-to-day lives today! Our lives are being impacted by robotics in so many different ways, many of which we would not even know of.

So, how exactly can robots improve or even alter how we live our daily lives? To begin with, domestic robots are becoming more and more common in houses across the world. These robots are designed to perform a range of tasks including housekeeping activities such as cleaning, dusting, and vacuuming, as well as caring for the elderly and differently-abled family members. For instance, the Roomba robotic vacuum cleaner is programmed to clean carpets, rugs, and floors and has gained a lot of popularity since its release in 2002.

Similarly, Wakamaru, a creation of Mitsubishi, provides assistive facilities to elderly populations that live alone. It is designed with a friendly face, and is compact, making it easy to use. Wakamaru can monitor the user’s health metrics, behaviours, and geographic location, and can notify family members and emergency services in case an issue is identified. Even in industries such as education, robots are being used to provide students in classrooms with hands-on technical experience while also allowing for longer periods of sustained attention and learning. The LEGO Mindstorms Robot Kit, for example, includes Lego blocks that students can use to create their robots. If you’ve been to an amusement park recently, you might also notice robots there that are being used to interact with and assist the guests.

If we expand our scope and begin looking at more widespread applications, we'd be surprised to know that robotics has entered almost every single industry from manufacturing and production to healthcare, defence, transportation, and even emergency services such as first responders. Among the most common industries where robots are used are manufacturing and production. Industries are using robots for a variety of reasons, including faster production, lower human error rates, preventative maintenance, etc. More specifically, robots are widely utilized in the assembly of automotive components to create advanced vehicles. Applications where a task must be completed repeatedly, such as nut-bolt tightening and brand-label wrapping, also use robotic arms.

Robots are also used extensively in the defence industry and associated fields including cyber operations, intelligence surveillance and reconnaissance, supply chain management, and logistics. These clever gadgets are employed for a variety of tasks, such as sniper location, missile control, and hostile area surveying. The most common type of robots utilized in military applications are surveillance robots. They are sturdy, adaptable, and little. Typically, they are equipped with a security camera that records, identifies, and, if required, alerts the controller to disorderly actions.

In a hospital, robotic technology offers a three-dimensional perspective, a surgical area that is ten times larger than before, and instruments that are more mobile than a human hand. The medical industry demands a high degree of accuracy and precision. Modern robotic operations are replacing conventional surgeries because the robots are less likely to make mistakes with human hands, including sliding the surgical blade from hands during a potentially life-threatening procedure.

Although it may still appear that robotics is far removed from the lives of many of us, who may not be working in factories, witnessing the medical impacts, or owning domestic robots, technologies such as face-recognition tools, and voice-controlled devices are also a large part of the field of robotics. This omnipresence is also evident by the fact that globally, the robotics industry is anticipated to develop significantly in terms of revenue, with a predicted value of US$38.24 billion by 2024. So, while we still may have a lot more to unfold when it comes to understanding robotics, the field is becoming to be among the quickest-growing markets.

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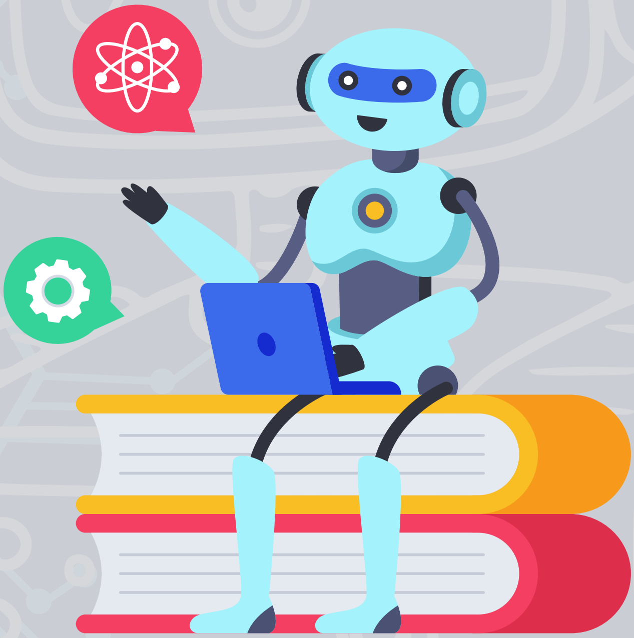
GETTING STARTED

So, now that we've understood just how impactful and pervasive robotics has become in our lives today, you might be wondering what goes into creating a robot, or how you can also become involved with robotics. While there are several different ways to go about this, which can all seem overwhelming, why don't we take a look at the basic steps that can help you get started with robotics?

Starting a robotics project or creating your robot is not very different from conceptualizing a business, product, or service. Although the knowledge and skills required will vary drastically, the process of getting started begins at the same point - Identifying a problem. This usually means you're going to have to become keenly aware of the different situations that you find yourself in, or others that you observe around you. When you get into the habit of doing this, begin asking yourself where robots or robotic interventions could improve the situation or solve a problem. For instance, you could identify a situation where human intervention is particularly risky, and the use of a robot capable of performing mechanical tasks could prevent severe harm or danger by replacing manual labour.

Once you've identified a possible problem, the next best step is to begin researching the industry and the area it fits within. This could involve analyzing previous interventions or innovations to understand how they succeeded, failed, or improved the process. This research is an important step that will ultimately guide your strategy and approach when you're building your robot. If you understand your problem well enough, then you can avoid repeating similar mistakes and concentrate all your efforts on new and more innovative solutions that have not been tested before.

Next, and this is the most important step, begin discussing your solution in depth. This includes getting the opinion and ideas of other people as well; whether it's from your peers in a brainstorming session or when discussing structured thoughts with key stakeholders like computer scientists or engineers. In case your issue is rather specific and individualistic it would also be good to talk with different specialists like developers, designers, healthcare professionals or other representatives of related industries.



Finally, a good knowledge of scientific concepts is required to be able to eventually build a robot. So, you must create a solid fundamental knowledge of the various kinds of technologies that are most frequently used to construct a robot. While there are many different concepts to know, artificial intelligence, sensor integration, and human-robot interaction are great points to get started with. Studying these concepts will prepare you for the final process of building a robot, as well as making your model substantially simpler.

This brings us to the last step of this process before actually building your robot - creating a prototype. This stage usually involves conceptualizing the broader structure and design of your robot, along with assessing where and how you will incorporate different technologies so that your robot can perform its final function. Working on a well-thought-out and detailed prototype will also help you get proper feedback from mentors or stakeholders that you consult with, which can prevent you from experiencing significant barriers or challenges during the later stages of building your final robot.

So, at a glance, here are the most important tips and tricks to getting started!

- Observe closely around you to identify a pressing issue that you could solve.
- Research gaps in existing solutions and technologies.
- Clearly define the problem as well as the goal of your robot.
- Follow each thought carefully before you dismiss or disregard them. Sometimes, the answers might lie in the least expected places.
- Discuss, discuss, and discuss your ideas with relevant individuals who can offer you guidance or advice.
- Build a quick yet detailed prototype to test your idea.

And, that’s your guide to getting started with your very own robot!

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UNWIRED: WHAT'S INSIDE MY ROBOT?

Having explored the basic knowledge one requires and the preliminary questions to think through before setting out to create robots, it is time to step into the real world of making robots. While this is no simple task by any means if one is familiar with the many individual parts that make robots what they are — starting from their external appearance to every internal aspect that makes robots efficient and smart, creating a robot will be easier than what you imagine it to be. A lot of research, thinking, and design efforts go into making a robot, and the first best step to learning the techniques to build a robot starts with breaking down everything that goes into making the robot itself — from the diverse sensors to the logic gates.

How do robots efficiently carry out various kinds of activities — be it moving from one place to another or picking up an object — with ease and on the drop of an instruction? The answer to this lies in the sensors that are used to calculate the condition and environment of robots, similar to how humans use sensory organs to understand themselves and their contexts better. Similar to how multiple sense organs come together to ensure humans can understand the world better, a variety of sensors are required by robots to navigate their surrounding environments and execute assigned tasks. Is there any particular type of sensor you are familiar with that goes into the making of robots? A few of the commonly used and important sensors are light sensors, sound sensors, temperature sensors, contact/touch sensors, Infrared (IR) sensors, proximity sensors, distance sensors, ultrasonic sensors, and so on. By delving further into each of these types, one can better understand their inner workings and functions better.

Fundamental to the functioning of robots are light sensors. Breaking down the name can perhaps help us understand what these sensors are. Primarily, a light sensor is a transducer used for detecting light. They operate by creating a voltage difference equivalent to the light intensity falling on a light sensor, and there are two main light sensors used in robots — photovoltaic cells and photo resistors. As important as a light sensor is a contact/touch sensor, similar to the sense organ of the skin in the case of human beings, that gives us a comprehensive understanding of the world by identifying the textures of things and helping us smoothly move from one place to another. The touch sensor's central function is to detect a change in the velocity, position, acceleration, torque, or force applied at the joints of the manipulator and the end-effector in robots. Commonly found in obstacle avoidance robots, these sensors require physical contact for their efficient operation, as upon the detection of an obstacle, a signal is transmitted to initiate actions such as reversing, turning, or stopping.

With the light and touch sensors in place, another important part of the robot is an ultrasonic sensor — a device that measures the distance of a specific object by emitting ultrasonic sound waves, eventually converting the reflected sound into an electric signal. Through the radiation of sound waves, these sensors determine the distance between the robot and an object and are commonly found in obstacle detection systems and anti-collision safety systems. In a similar vein, robots also make use of infrared (IR) transceivers — devices that measure and detect infrared radiation in their environment. With these fundamental sensors, we have deconstructed the primary structure of a robot, and now it's time to begin our journey of making one.

The first step towards building a robot, like any piece of invention or innovation, is to know the primary purpose for constructing it. This, along with identifying the specific requirements that the robot must fulfil, is the first step towards ideating the design that the robot must execute. The first step is to gather information through research about what the practical function of the design is — that is, everything including the movement, manipulation, energy, intelligence, and sensing capabilities of the robot. This is followed by thinking about the appearance of the robot: factors such as its shape and form, surface texture, colour, etc., to decide what the robot will look like. With the primary intent and a clear idea of the robot's potential design in place, the next important step is to decide the material that is most suitable for the design. This requires one to factor in the strength, hardness, toughness, density, durability, and aesthetic qualities of the material. With the right material chosen, the next step towards building your robot is to select the method that is the most appropriate to execute the design with the utmost finesse.

The construction techniques behind building robots fall into categories such as cutting and shaping, fabrication, moulding, and casting. While fabrication is the assembly of the different parts using screws, bolts, and glue, moulding is the application of a force on the material, followed by casting — the use of a mould to form the shape of a solidifying material. It is based on the chosen material the method of construction is decided. Today, along with these core steps, it is also imperative to incorporate one more strand of thought in conceptualizing your robot — careful thinking about the social and environmental effects of the design. With these fundamental steps, you can begin the journey of making your robot.

Having broken down the sensors that make a robot to figure out how to build them from scratch, looking at one more technique helps build robots today — sensor fusion. Sensor fusion merges data from multiple sensors on and off the robot to reduce uncertainty as a robot navigates or performs specific tasks, increasing the accuracy, reliability, and fault tolerance of sensor inputs. Thus, the journey of building robots is a dynamic and evolving process, and staying updated with modern technological advancements can help us build efficient and smart robots.

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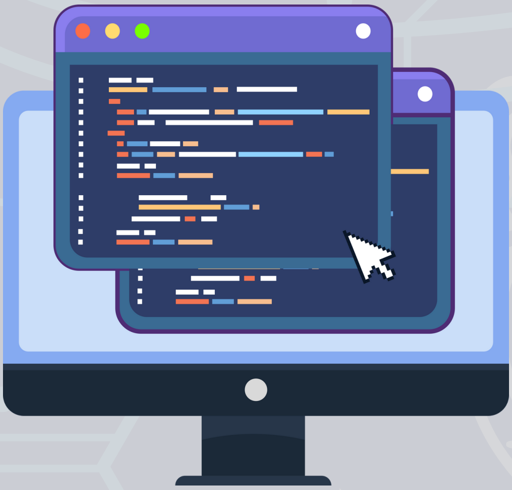
CIRCUITS TO SYNTAX: PROGRAMMING LANGUAGES FOR CREATING YOUR ROBOT

As we speak about designing a robot, one way of articulating the process of design is to refer to it as "programming" the robot. As this expression is often used interchangeably, the question of "What does "programming" signify here?" becomes pertinent. How exactly is it that we program robots? The answer to this can be found in the key that fuels the design, functioning, and overall operation of robots — programming languages. It is through the use of programming languages that developers control the behaviour, logic, and communication of robots, building efficient and high-performance robots. If you're familiar with programming languages, it is quite likely that you have heard of C++, Python, Java, and ROS, and these programming languages, time and again, have been effectively used in building robots.

The most fundamental and widely used programming languages, C++ and Java have been instrumental in shaping the domain of robotics in today's world. While C++ is a low-level language that offers high performance along with direct access to hardware and memory management, Java is a high-level language that offers portability, simplicity, and object-oriented features. With both programming languages having their pros and cons, looking at alternate programming languages can be a useful option, and Arduino can offer some insights into tapping into the world of creating smart robots. What is Arduino? To begin with, it is a language designed to make it easier to write programs for microcontrollers, which are small, low-cost, low-power computers that control physical inputs and outputs.



This open-source hardware development platform has been used, time and again, to design and build electronic devices that interact with the real world, making it an efficient solution in many different areas, ranging from hospital management systems to credit card payment systems. A microcontroller board with an entire computer on a chip — everything from the processor core, memory, and input and output controls, Arduino was first created to help students without a technical background, making it a reliable means to step into the world of robotics.

How do we build an Arduino robot? The answer to this begins with the core steps in creating a robot that was discussed in the previous chapter, with the primary change being incorporating the programming language at hand into the standard process. Firstly, once the materials and tools are ready — which could include a wide range of items, starting with an Arduino microcontroller board and a motor shield, one can officially begin the process of making a robot.

If this is a simple homemade robot, the motor shied that is made will be connected to the Arduino and it will be powered. Though these steps might seem complex, Arduino is undoubtedly one of the most accessible programming languages out there, and with the choice of the right Arduino kit and a clear idea of the purpose of the robot, the steps ahead will be easier than what one may anticipate.

While thinking about creating a robot, what is the most confusing aspect of the creation process? One complex aspect of the process of creating robots is the technical prowess it demands, particularly in today's constantly evolving world. Object-oriented programming is one style of programming that helps understand today's programming landscapes better. A programming style wherein you create multiple smaller occurrences of programs that act on their own, OOP is a major part of all programming that also forms the crux of Java.

A step ahead of the unique solutions offered by OOP is another innovation referred to as robotics middleware. Fundamentally designed to manage the complexity and heterogeneity of the hardware and applications, robotics middleware integrates new technologies to simplify software design and hide the complex of low-level communication and the sensor heterogeneity of sensors to improve software quality, reuse robotic software infrastructure across multiple research efforts, and to reduce production costs. These benefits, as listed by Ayssam Elkady and Tarek Sobh indicate the promises opened up by robotics middleware in today's world. Real-time Operating Systems (RTOS) are another innovation that one has to discuss while going over modern robotics as this operating system, built upon the key features of predictability and determinism, helps perform repeated tasks within a tight time boundary in the most efficient way possible.

Programming languages are key to the functioning and productive designing of robots, and by choosing the language that best fits your interests and needs, the journey to building robots will become easier to navigate.

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OPTIMIZING OUTCOMES: WHERE DO I START?

A robot is an automated machine designed to reduce the use of human effort. As such, a robot may or may not resemble a human in appearance: in fact, most robots do not, as our world today has witnessed the creation of many different types of robots, in an extremely wide variety of shapes and sizes.

Robotics then is a multidisciplinary branch that exists at the intersections of engineering and computer science and deals in the design, construction, operation, maintenance, and repair of robots.

So before we embark on the thrilling adventure of making a robot, which is surely gonna be a learning-filled and thrilling enterprise, here is an insightful bit of trivia for you. Did you know that the word robot derives from the Czech word *robota* which ranges in meaning from “serf” to “forced labour”?

By utilizing various strategies to optimize various outcomes, our goal here is to develop a robot that not only performs elementary functions but is also user-friendly and accessible for us to make.

A robot requires both hardware, the physical components, as well as software, the programming that allows it to execute different functions.

Firstly, you would need to assemble all of our equipment or the hardware of the robot. These commonly include the following:

1. A power supply to provide electrical energy to the robot.
2. Actuators, are motors that convert electrical energy to mechanical energy, enabling the robot to move.
3. Sensors that help the robot detect changes in its environment, such as motion or pressure, allow it to adapt its movement.
4. A control system that processes the input from the sensors and instructs the robot what to do next.
5. A controller which allows a user to program the robot and control its actions.
6. End effectors that allow a robot to engage and interact with its environment. Examples of end effectors are grippers or drills.
7. A body and frame, which is the physical structure of a robot holding all of its different constituents together.

The first thing you need to do is to design your robot. This is one of the most fun parts of the entire process, as you get to sketch a robot according to your likes and preferences, and make it as cool as you want it to be. Designing the outline of your product is important because you not only get an estimate of its shape and size but also get an idea of where each of its constituent electronics would be placed.

Building different kinds of robots requires different kinds of materials. While creating some robots requires you to code extensively, others can be developed without the use of any code at all. This depends on several factors, such as your age, skill level, and cost considerations.

To then build a robot, what you need, most of all, is a robot kit, which comes with all the necessary parts and instructions to allow you to create your very own robot. It is best to buy a beginner-friendly robot kit on your first attempt to allow you to create a robot with ease. After familiarizing yourself with the several details of the kit, including its different components and the prescribed steps, begin following the instructions on the kit. While specific instructions should vary according to each kid, broadly, they should take the following order:

- **Building the robot's chassis**

Assemble the body of the robot according to specific instructions outlined in the instruction manual, for example, securing the motors in the designated place, or installing the wheels onto the shaft of the moto. Do not forget to install the battery which would act as the power source of the robot.

- **Connecting the Electronics**

One of the most thrilling steps in making your robot is the wiring process. While working with wires, it is best to be extra careful while cutting them using sharp objects. Also, remember to connect positive terminals and negative terminals. Your robot will not work if you connect a positive terminal to a negative one.

- **Testing the robot**

When you turn the robot on, carefully observe its functionality. If you are working with a simple robotics kit, your robot will probably be able to move forward, backwards, left, and right. Make sure you test if your robot is responsive.

These are the elementary steps required for creating an elementary robot. Once you can build a robot of this kind, you can begin experimenting with different designs to be able to design robots that execute different tasks.

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TRIAL, ERROR, AND SUCCESS: TESTING OUR ROBOT

The engineering design process is a structured methodology that follows a series of well-designed steps that allow users to bring their ideas to fruition. Therefore, the design process—covering a whole range of elements, from identifying the problem to ideating a solution and then implementing it—plays an instrumental role in making our world a better place.

Therefore, in robotics too, the engineering design process plays a crucial role, in helping us create better and more robust robots. By emphasizing open-ended problem solving by letting users work at gaps in their design at their own pace and without additional help, the design process helps students learn progressively from their mistakes and devise truly innovative solutions.

Importantly, the engineering design process is iterative, which means that it requires users to repeat steps as many times as needed and make improvements gradually over each iteration. Similarly, when we approach robot implementation as an iterative process, we will constantly code, and then run the code, before coding again to run the updated code once more. This constant process of alternation between coding and running is precisely the testing process. In this chapter, then, we shall learn about some kind of test runs that we can perform on our robots to build better prototypes, and plug critical gaps in design.

Following this method is extremely important because when we add new functionality to a robot, we will notice that a bunch of issues crop up immediately, requiring us to address them. This is why we cannot simply test the robot after having made the entire robot because that would result in an endless number of issues. Instead, we need to run tests after adding each functionality using an iterative approach.

There are a range of tests that should be conducted on a robotic system to be able to evaluate its competency and success. Some of these tests include component-level testing, which is composed of tests like use, thermal, power, endurance, stress, and wheel testing. Let us explore examples of each of these tests.

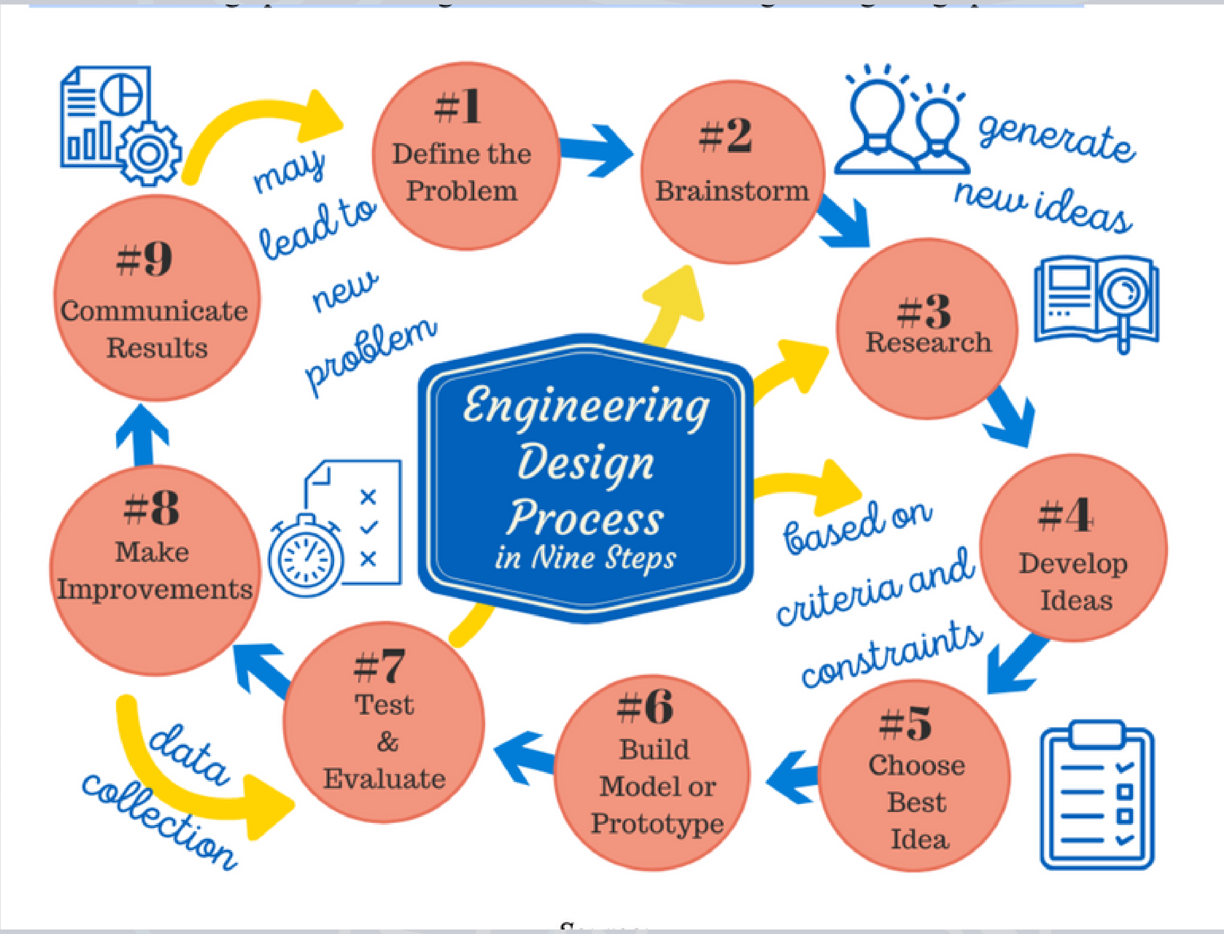
A use test is meant to check if the system works, for example, if it is meant to pick 20kgs, a use test checks if it can it do that. A thermal test checks the temperature tolerance of a robotic system to both high and low extremes. A power test allows us to find the power used by each component of the system to allow us to gauge the size of the batteries it will require. As its name suggests, an endurance test is meant to evaluate how long a robotic system can continue performing in realistic conditions. Similarly, a stress test judges the ability of the system to perform under extremes.

Other additional tests allow us to adjudicate the usefulness of a robotic system by evaluating it using different metrics. For example, a slope climbing test is useful in letting us know whether a robot would be able to move on slopes, while an obstacle avoidance test allows us to test whether a robot can prevent colliding with the obstacles in its path to see if it could navigate around trees, rocks, as well as holes or cliffs.

Always ensure that all of your tests are conducted systematically. For this, it is best to use a checklist to review the different conditions that are met before you begin your test.

In the engineering design process, it is of extreme importance to clearly define the objectives of your test and to be clear on the exact functionality that is under review. Additionally, systematically collect your data after each test run, including your observations, and data from sensors, as well as any anomalies you witness. Use this data to create patterns and generate insights for improvement. Incorporate these insights in the iterative process to tweak your hardware and software to be able to progressively perfect your design.

Look at the infographic below to get a clearer idea of the engineering design process.



Source: https://cariwilliamzvex.weebly.com/uploads/4/1/9/2/41923069/engineering-design-process_orig.png

Now that you've built and tested your robot, it is time to set a maintenance plan to action to help your robotic system maintain its efficiency and eliminate any equipment failure, thereby improving longevity. Here is a list of some things that you can do to maintain your robot's efficiency:

1. Properly grease the joints and gears used in your robot.
2. Keep the base of your robot clean, and remember to remove any accumulated dust from the space between parts.
3. Clean sensors and camera lenses.
4. Routinely check if all the bolts are tightly secured.
5. Replace your batter regularly.

Thus, you are now familiar with the dynamic process of engineering design that helps you fix the little imperfections in your design to create a truly formidable robotic system.

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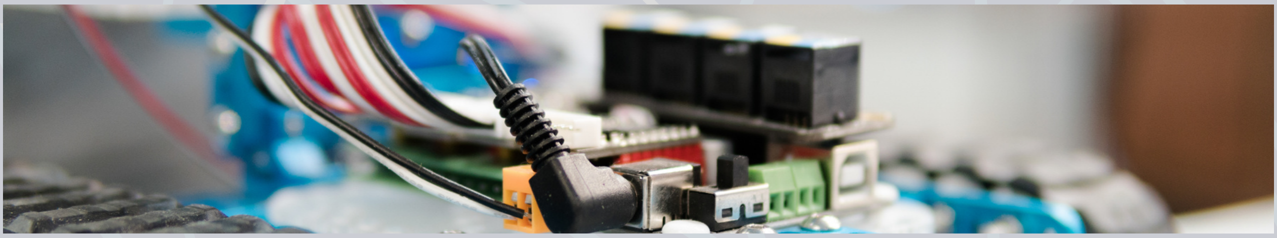
BEYOND THE BOT: MOTION PLANNING AND ADVANCED FUNCTIONS



The field of robotics continues to push the boundaries of innovation: over the last couple of decades, we've seen robots go from simple, task-specific machines to more sophisticated systems that are capable of complex interactions. Throughout the past few chapters, we've delved deeper into how to build a basic robot, from the hardware components required to the programming language one has to be familiar with. Another essential concept to explore here is motion planning: this is the process of breaking down the desired movement of the robot into discrete movement tasks, keeping into consideration possible constraints to the movement and optimizing the process as much as possible. In simple terms, it involves determining the optimal path and sequence of movements for a robot to perform a specific task.

A few examples might make this simpler to understand. If we were to envision a robot that starts its journey from inside a building to reach a defined endpoint in the distance, it would need to be able to climb down stairs and avoid any obstacles (or building structures like a wall) while making its way there. Industrial robots perform these kinds of complex tasks regularly: for instance, SCARA or the Selective Compliance Assembly Robot Arm is used for pick-and-place operations or any kind of assembly system where a high degree of accuracy and speed is necessary.

There are several types of robot motion. Linear motion is the most intuitive since it implies straight-line movement from Point A to Point B. This is useful when the robot is in a very confined space and cannot be allowed too much freedom in movement. The second kind of motion is Point-to-point motion, also called joint motion. The result of this motion will be the same as linear motion, but the robot will not necessarily move in a straight path here. With this kind of motion, the robot will choose the fastest path, even if it's not the shortest one. The major disadvantage of joint motion is that the robot's path is harder to predict, so one needs to put in extra effort to ensure there are no issues during the movement. However, it is extremely versatile since it can be employed in both abundant and limited space. The last kind of motion we'll discuss here is circular or arc motion, where the robot moves in a constant radius. Oftentimes, a full circle is not needed to achieve the objective, and it might be designed to complete a finite arc. This is often used in milling, welding, and glueing applications.

How are these kinds of motions achieved? Well, usually through a motion planning algorithm that charts out the path the robot will take. Interestingly, we all use motion planners every day on our smartphones. Whenever we open a navigation app and input our start and end locations, we're instructing our device to find the 'best' path for us - which could be either the fastest or shortest path, depending on our goals. When we identify the goal for our robot, such as object separation in waste management robots or light-following robots that can be used for quality control, we can choose the right motion planning algorithm. This would provide pointers for configuration space, free space, and path planning, along with load capacity and rigidity depending on the complexity of the project.

Whether it's navigating through cluttered environments, avoiding obstacles, or mimicking human-like movements, an adept grasp of motion planning and kinetics becomes essential for engineers who are striving to push the boundaries of what robots can achieve. Furthermore, as robots become more sophisticated, their interaction with humans becomes increasingly important. Many computer scientists are exploring how these machines might be able to understand human speech and texts. Machine learning and natural language processing become major assets here since they can be trained on large datasets and determine results with a high degree of accuracy. The idea is that robots must be adaptable to diverse environments and be extremely easy for users to use, even those with limited technical expertise.

We are experiencing an unprecedented degree of technological integration in our lives, and any development (and deployment) must also include ethical considerations - such as those of data privacy, transparency and accountability to mitigate the black box problem of algorithms, and policymaking to address potential job displacement. Only with this mindset can revolutionary innovation be centred around fulfilling human needs and improving people's quality of life.

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