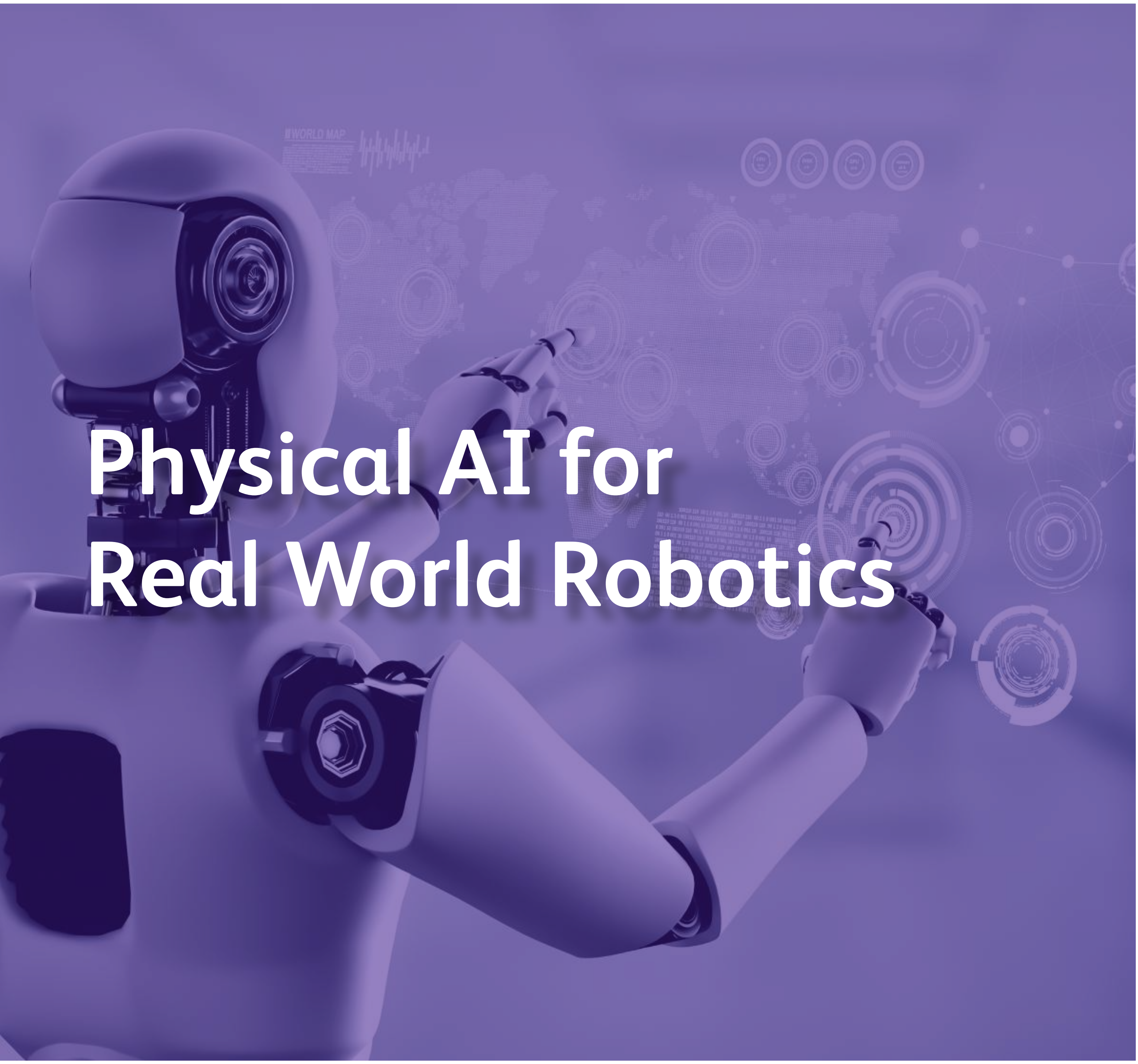
Technology
Innovation
Institute



Physical AI for Real World Robotics

Abstract

Humanoid robots, once confined to science fiction, are poised to reshape industries and daily life in the near future. The global market, projected to rise from approximately $2 billion USD currently towards a potential $38 billion USD by 2035, reflects the immense opportunities in this sector. The Technology Innovation Institute (TII), a leading global scientific research center and a pillar of Abu Dhabi's and the UAE's advanced technology ecosystem, is committed to achieving functional humanoid robots that are useful, cost-effective and welcomed by their human partners. This white paper details TII's unique vision and methodology for reaching this goal, as embodied in its strategic humanoid initiative.

The initiative is grounded in three key principles:

"Physical Artificial Intelligence"— understanding and planning capacity that is gained through direct interaction with the physical world.

Multi-Part Development — rigorous focus on the separate software and hardware components that will combine to make a successful humanoid in the near future.

Real World Iteration — testing and improvement of these components in warehouses, restaurants and other "real world" settings.

The first principle is a commitment to robotics grounded in the real world, not in simulations.

The second acknowledges that a humanoid robot must integrate many different technologies and insights. Like an F1 team principal who assembles drivers, engineers, and pit crew members — each trained and tested to perform well under extreme conditions —TII's strategy is to simultaneously foster a diverse range of robotics solutions, which will ultimately converge in a finely balanced, high-performance humanoid robot.

The third principle follows from TII's commitment to developing technologies that are useful right now, in the "real world" outside the lab.
Together, the three principles ensure the creation of robust and practical components that will combine to make truly useful humanoid robots – humanoids that perceive their environment, move around, manipulate tools and objects, and learn from their experiences, as they work side-by-side with people.

This is TII's ultimate goal: Reliable, cost-effective, and versatile humanoids that augment human potential and contribute meaningfully to society and the economy, both within the UAE and globally. This white paper describes the challenges of making useful, scalable, robust humanoid robots, and then explains the strategic rationale, technical underpinnings, and anticipated impact of TII's three-part strategy.

Introduction:
The Dawn of Real-World Humanoids

From ancient myths of automata to modern science fiction depicting robot companions and workers, humans have long dreamed of creating artificial helpers in our own image. Advances in industrial robots over the past 70 years transformed manufacturing and other sectors, but they did not satisfy those hopes. Today, most of the world's robots look nothing like us.

Yet the world is built for people. Our homes, workplaces, stores and vehicles are designed for the human form. Many kinds of labor can only be performed by workers shaped more or less like people. Only humanoids can promise to mirror human abilities and do human work, enabling people to transcend our limitations and automate tasks that are dirty, dangerous or dull.

In recent years, practical humanoid robots—characterized by safety, cost-effectiveness, worker acceptance, and affordability—have become possible. This is the result of breakthroughs in component design, energy storage, sensor technology, materials science, and particularly Artificial Intelligence (AI). AI advances in machine learning, computer vision, and natural language processing have turned humanoid robotics from a theoretical possibility into a practical field. All over the world, prototypes from research institutions and corporations now exhibit increasingly sophisticated locomotion, manipulation, and interactive capabilities. This has fueled a surge in interest from investors, industry, and the public. Hence, market analysts forecast exponential growth for humanoid robots in the coming decade. The world humanoid robot market is expected to be worth $38 billion by 2035, with a Compound Annual Growth Rate exceeding 40 percent.[1] Public interest has also surged, with online mentions of "humanoid robots" increasing more than 300 percent since 2021.[2] The UAE, a high-income, high-tech nation whose population is expected to grow by 44 percent between now and 2050, is a natural growth market for robots that make work safer and more efficient.[3]

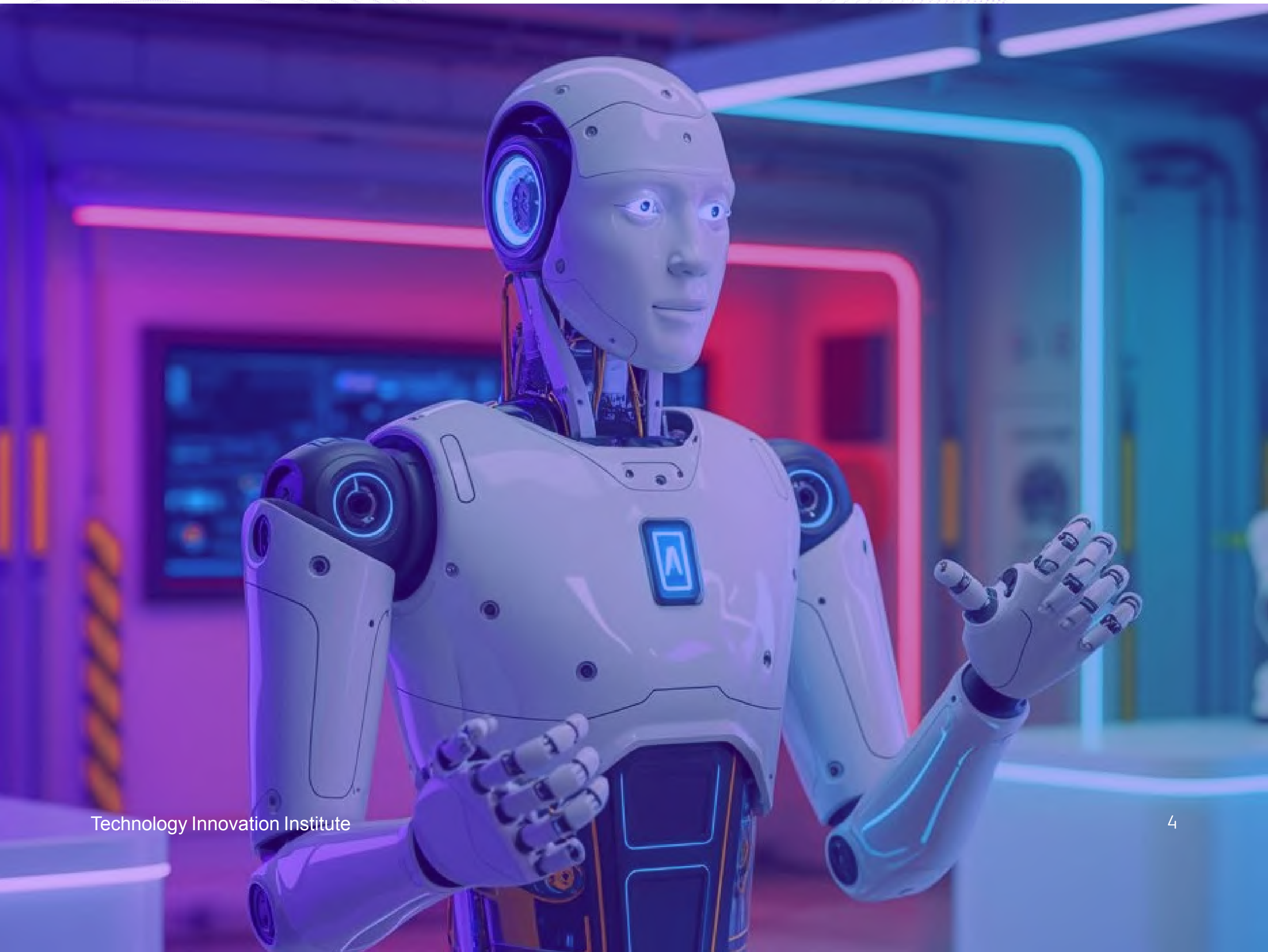
The potential benefits of real-world humanoid robots are profound. Unlike current robot technology, they could integrate seamlessly into existing workflows in manufacturing, logistics, healthcare, and service industries, among others. In spaces where other types of robot are not practical or possible, humanoids could undertake tasks that are dangerous, repetitive, or require levels of precision and endurance beyond human capacity. That would free human workers to focus on more complex, creative, and strategic endeavors. Hence, humanoids are key to realizing the fundamental goal of robotics: to alleviate the burdens of physical labor and enhance human potential. This is a vision of robots that are more than tools, in a future where humans and intelligent machines collaborate to augment each other's strengths.

1«The global market for humanoid robots could reach $38 billion by 2035.» Goldman Sachs, https://www.goldmansachs.com/insights/articles/the-global-market-for-robots-could-reach-38-billion-by-2035.
2 «Humanoid robots." Google Trends, https://trends.google.com/trends/explore?date=2021-01-01%202025-05-26&geo=US&q=humanoid%20robots&hl=en-US, retrieved May 25, 2025.
3«United Arab Emirates.» datadot, 22 Nov. 2022, https://data.who.int/countries/784.

Introduction:
The Dawn of Real World Humanoids

TII's strategy leverages the institute's strengths: its world-class achievements in computer vision, secure systems, and autonomous robotics. These and other technologies, tested and refined incrementally in real world settings in logistics, construction, and healthcare, will form a robust software and hardware foundation for humanoid platforms. Deploying varied capabilities, in a range of enterprises, yields insights in three essential areas of humanoid robotics research: the technical and practical features of the components; the experiences of human beings as they work with robots (Human-Robot Interaction); and the ethical safeguards required to ensure that robots are trustworthy and safe.

TII's vision for humanoid robotics aligns directly with the strategic objectives of the UAE. By pushing the frontiers of AI and robotics, TII contributes to the nation's goal of becoming a global hub for technological innovation and a knowledge-based economy.



The Challenge:
Getting From Lab Demonstrations to True Utility

Despite remarkable recent progress and palpable excitement, humanoid robot capabilities, when showcased in controlled laboratory settings or choreographed demonstrations, are far from meeting the demands of widespread, reliable real world deployment. Current humanoid prototypes often face significant limitations in terms of:

Robustness and Reliability: Operating consistently in unpredictable, dynamic environments poses immense challenges compared to structured labs. Dust, uneven terrain, water, unexpected obstacles, and variable lighting conditions can easily overwhelm current humanoid systems.

Energy Efficiency and Autonomy: Battery life and energy consumption often limit the amount of time a robot can operate usefully.

Cost-Effectiveness: The cost of developing, manufacturing, maintenance, and computation for sophisticated humanoids is currently prohibitive for mass adoption.

Adaptability and Learning: Generalizing skills learned in one context to novel situations remains difficult for robots.

Safety and Human Interaction: Humans must be safe as they interact with powerful robots. Moreover, robots have to be psychologically safe intuitive to use, predictable and socially adept enough for people to be comfortable working with them. Literal and psychic safety are essential to trust and adopt. Neither of these challenges has been overcome.

Scalability: There are still significant engineering and supply chain hurdles to any transition from a bespoke humanoid prototype to mass-produced, commercially viable robots.

None of these challenges can be met just by continuing incremental improvements. Instead, they require a strategic approach that grounds development in real world constraints and requirements. This is the approach of the Technology Innovation Institute (TII).

Why And How to Develop Humanoids

Developing advanced humanoid capabilities can attract top international talent, foster local expertise, create high-value jobs, and spin off new industries. Furthermore, the potential applications of these technologies in sectors critical to the UAE (such as logistics, construction, energy, and healthcare) promise significant economic and societal benefits, enhancing efficiency, safety, and quality of life. TII's commitment to building real world humanoid robots serves as a tangible demonstration of the UAE's ambition and capability in advanced technology.

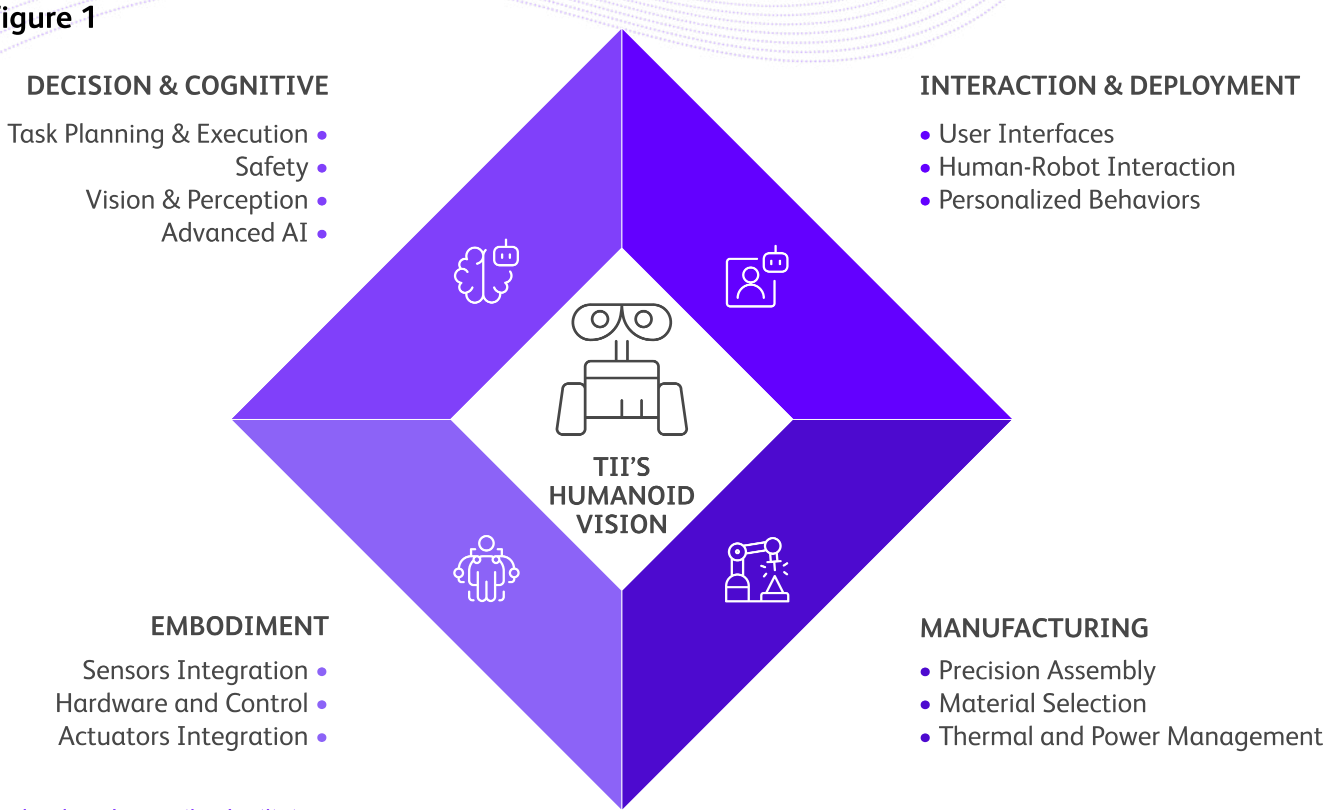
The Institute's three principles of humanoid development are central to this strategy. They form a commitment to a practical, learning-driven methodology rooted in solving tangible problems within the UAE context. Rather than pursuing a purely theoretical or isolated "moonshot," TII aims to build increasingly complex capabilities incrementally, ensuring that each stage of development is grounded in empirical data and real-world validation.

Understanding the Challenges

What is a humanoid robot?

A "humanoid" is, loosely speaking, any robot which resembles the human body shape. Unlike most robots, a humanoid is designed to interact with the world as we do. This makes it capable of keeping us company in houses and hospitals, assisting us in daily activities, helping us with work tasks and so on. A typical humanoid shape (and the many uses to which it can be put), is shown in Figure 1.

Figure 1



Why And How to Develop Humanoids

Though a humanoid comes closer to human form than do other robots, it remains profoundly different from a person. First, at the fundamental, chemical level, robots today are made of plastics, rubber, and aluminum, iron, copper and other metals. Our bodies, in contrast, consist primarily of carbon-based organic molecules.

For this reason, designers and engineers never seek to copy humans in robot form. The goal is, rather, to design a functional machine of human shape that is good enough to do what we expect it to do, and that can be priced at a cost where companies and people will want to use it.

How A Robot Works

A robot is made of sensors, actuators, a computer (or computers), a body, and a power source. All play a role in formulating its planned actions.

Sensors: A robot perceives the world with sensors – among them cameras, lidars (laser range finders), accelerometers, force sensors, microphones, tactile sensors, temperature sensors, and others. Some of these sensors are proprioceptive – they tell the robot about its own status (for example, if it is moving up an incline); others are "exteroceptive" sensors, which convey information about the robot's environment (for example, if there is a wall in front of it).

Each of these sensors is part of a local network that uses them to reproduce essential perceptions – a sense of balance, and senses of sight, hearing, touch. Even smell and taste can also be engineered in a robot with dedicated equipment, for instance to detect a gas leak.

Actuators: The next key element of a robot body consists of its actuators, the robotic equivalent of muscles. They are electric motors in different forms (they may rotate or move along a straight line) and provide the torque or force necessary for the robot to move its arms, legs, hands, neck, and every other part of its body.

The "Brains": Both sensors and actuators report to, or are controlled from, one or more computers. Some are inside the robot. This computer can be thought of as the brain of the robot. However, it is impossible to have all robot intelligence deployed on one brain at the same time. So it is common to offload part of the computations to servers, which can be close to the robot or in the cloud. This can be thought of as the robot asking for advice, say, from ChatGPT, to perform a task it doesn't immediately "understand."

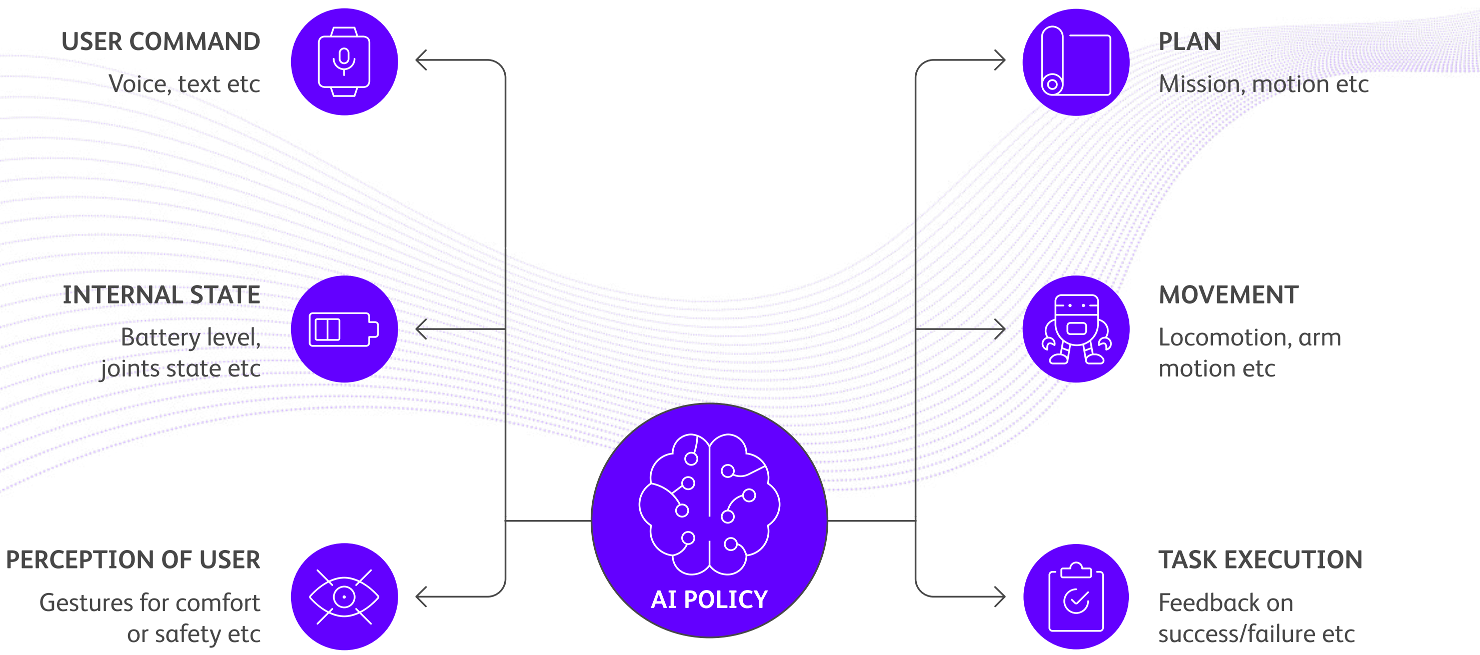
The Body: The internal structure that supports the robot, and the outer shape that defines its presence and interaction with the physical world. This is what gives AI its physical attributes, allowing it to interact with the world .

The Power System: The robot is powered by onboard batteries, which are integrated into the system to monitor charge levels and signal when recharging is needed.

The Policy: The four systems above are all engaged in the process of formulating a "policy" — the robot's plan for performing a task. A policy takes certain inputs, like user vocal commands, gestures, measures of the internal and external state of the machine and its surroundings, and computes certain output actions, which can be a sentence, a movement, or a plan to go from the entrance of a house to the kitchen. (See FIGURE 2)

How A Robot Works

Figure 2



Putting It All Together:
Humanoids as the Ultimate Integration Platform

Integrating all these functions is a challenge in any robot project. It is even harder for a humanoid. Compared to other robots, humanoids must be more versatile (because people's workplaces and homes change more quickly, and are more unpredictable, than a typical factory floor); and more sophisticated (because humanoids must perceive and manipulate the wide range of objects humans use). The simple act of walking on two legs creates challenges for robot designers that other machines don't face: reproducing the many unconscious adjustments that humans make as they walk is much more difficult than making a robot that uses four legs, or wheels, to get around.

Hence, TII views the development of humanoid robots as an "ultimate integration platform" for a wide spectrum of robotics and AI technologies. Developing a successful humanoid requires integrating solutions for six fundamental research challenges:

Advanced Locomotion: Stable and efficient bipedal walking, running, and navigation across varied terrains.

Dexterous Manipulation: Handling objects of different shapes, sizes, weights, and textures with precision and appropriate force.

Environmental Perception: Rich, real-time 3D understanding of surroundings, including object recognition, localization, and semantic interpretation.

Human-Robot Interaction: Natural, intuitive communication and collaboration with humans.

Complex Reasoning and Planning: Understanding and planning execution of tasks, decision-making under uncertainty, and long-term planning.

Learning and Adaptation: The ability to acquire new skills, transfer known skills to novel situations, and adapt to unfamiliar environments. Humanoids cannot be programmed exhaustively in advance for every possible scenario in a kitchen or a construction site. Therefore, they must be developed to autonomously learn and improve through interaction. Today, humanoids lack sufficient computational power to run AI that can cope with real world surprises. Accordingly, TII has worked with a leading manufacturer of high-end Graphic Processing Units — the chips used for intense AI applications — to create hardware for each robot that is capable of more computation than is currently available.

By tackling the humanoid challenge, TII aims to drive progress in all six of these fundamental areas. The resulting technologies will not only be essential for humanoids. They will potentially be applicable to a broader range of robotic and autonomous systems. The humanoid form-factor acts as a demanding, unifying goal that pushes the boundaries of current capabilities on many fronts.

The Three Principles in Action:
Physical AI, Multi-Part Development, and Real-World Iteration

Physical AI: Intelligence Forged Through Interaction

To progress on all six of these fundamental research challenges, robot research cannot be conducted in virtual reality. Robots must engage with the real world. This is the reason that TII's first principle of humanoid development is "Physical AI."

Physical AI is a departure from the dominant paradigm in artificial intelligence: Learning from vast, static datasets of text and images. Just as it is easier to dream of cooking a fine meal than it is to actually make one, so it is easier for AI to create recipes, images and videos of cooking than it is for a robot in a real kitchen to succeed at this complex task. But only work in a real kitchen counts as success for a humanoid.

TII researchers base their work on the conviction that robots, to know about real life, must be able to learn from real objects and real spaces. They will need to understand an object's physical properties: its weight, texture, fragility, how it behaves when pushed or lifted, its affordances (what can be done with it), and the consequences of interacting with it. This understanding cannot be fully captured by statistical correlations in data or simulations; it must be learned through active engagement – pushing, pulling, lifting, observing outcomes, and building internal models of physics and causality grounded in sensory feedback. This is Physical AI: the development of intelligence through direct, embodied interaction with the physical world.

Physical AI builds its representation of the world based on the robot's own experiences, as it perceives and acts in the same spaces humans do. Compared to work done only in simulation, the Physical AI approach promises to yield AI that is:

More Robust: Less vulnerable to situations that aren't in the robot's training data.

More Adaptable: Better able to generalize knowledge and apply skills in novel situations because its understanding is based on underlying physical principles rather than superficial patterns in data.

More Data-Efficient: Capable of learning effectively from fewer interactions because each interaction provides rich feedback along multiple paths (vision, hearing, touch and others), all directly relevant to the physical task.

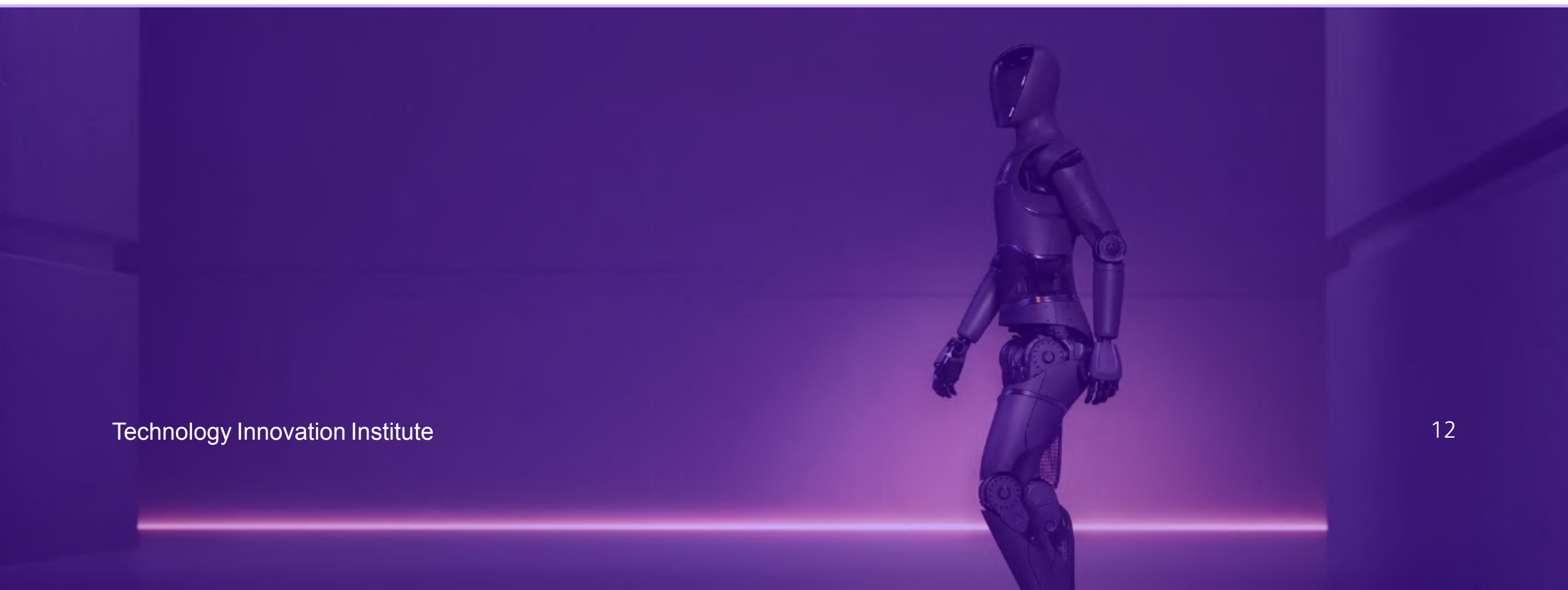
Multi-Part Development

Achieving "physical AI" through embodied experience could be achieved by "top-down" approach. That is, researchers could define a highly ambitious humanoid form and its functions from the outset, and then attempt to develop all necessary subsystems simultaneously. Despite its potential for "moonshot" breakthroughs, this approach carries significant risks: high upfront investment, long development cycles before demonstrating tangible value, and the complex demands of integrating different functions. Any of these can derail progress. Moreover, because the real-world product must unite all the subsystems, it cannot be deployed in real workplaces, until every single component has been perfected. This deprives society of the benefits of ongoing research, and it deprives researchers of the chance to learn from practical experience.

TII has chosen a different path, embodied in its second principle: Multi-part development. The strategy identifies the fundamental building blocks for a humanoid robot and develops them simultaneously. Like a coach who recruits diverse players with different skills in order to assemble a winning team, this strategy allows each component to improve. Eventually, this "multi-player recruitment" will lead to solutions that can be combined into the ultimate goal – the working humanoid robot.

This strategy involves much less wait time for useful results. On the path to the final goal, it will produce simpler robots that can be deployed right away. That promises reliable advances in the shorter term: results that offer technological insight and practical tools for the real world, without losing sight of the "ultimate integration challenge." The strategy will produce rigorously-tested solutions for each of the six challenges mentioned above –solutions targeted at specific, potentially profitable applications within the UAE.

The strategy allows TII to leverage foundational technologies developed across its research centers. For example, TII possesses significant capabilities in AI-driven perception and computer vision, crucial for enabling robots to understand and navigate their surroundings. These areas of TII expertise include real-time object detection; semantic segmentation (understanding the category of each pixel in an image); the accurate perception of a three-dimensional object from 2D photo, video or LiDAR images; and sensor fusion (combining data from multiple sensors – for example, integrating sights with sounds).



Finding Common Ground Among Diverse Components

The benefits of multi-part development flow in both directions. Progress on separate components contributes to the overall goal of integration into a humanoid. And that goal, in turn, spurs researchers to seek the common ground that can make components more efficient. For example, TII researchers are developing a "unified software stack" – software modules for different robots that share common interfaces and architectures. The goal is to create software components that are reusable across different robot types, including the eventual humanoid. This approach promotes modularity, simplifies integration, and enables TII's software innovations to benefit a wide ecosystem of robot types. In the future, this could include contributions to internationally used open-source robotics frameworks (like the widely used Robot Operating System 2)

TII researchers are enabling robots to:

Understand Natural Language Instructions: Processing complex, context-dependent commands from humans (e.g., "Go to the kitchen, find the blue mug near the coffee machine, and bring it here").

Perform Contextual Reasoning: Using common-sense knowledge embedded within the robot brain to infer humans' intentions ("the blue object is a glass, not a mug, does the human still want it?") or resolve ambiguities in tasks ("what does 'near' mean?").

Facilitate Task Planning: Breaking down high-level goals ("prepare this for shipment" into sequences of executable actions ("first, weigh the object, second, place it in shipping box").

Enable richer Dialogue: Engaging in more natural and informative conversations with users about tasks, status, or environmental conditions. High-level linguistic understanding has seen remarkable advances in LLMs in recent years. A key goal of robotics research is to bridge the still significant gap between computers' high-level understanding of language and the low-level processes that control robot movements. Robots know how to move their arms and grippers; but they also need to know that an orange is heavier than a balloon but softer than a cricket ball. Connecting those two kinds of knowledge is the key to making a robot that creates the right "policy" to carry out a command like "pick up the orange" – without dropping the fruit, or crushing it.

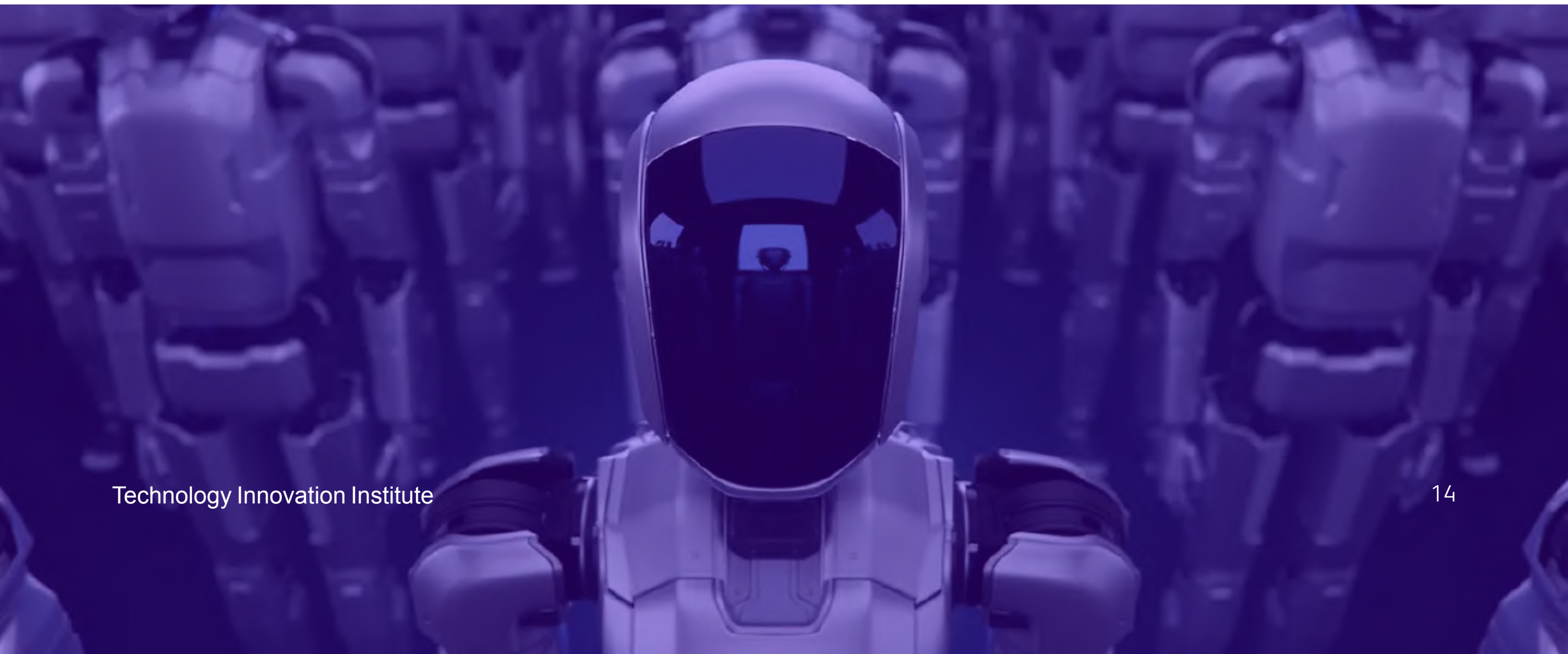
Integrating Components into a Team

TII's Physical AI approach complements and enhances its research's contributions toward practical humanoid robots. While TII's perception research provides the rich sensory input, physical interaction provides the feedback loop between robot planning, robot perception of its environment, and robot perception of the effects of its actions.

When the robot attempts an action (e.g., grasping an object identified by the vision system), the physical consequences (success, failure, slippage detected by sensors) provide grounding data. This data refines both the robot's physical control system and, potentially, the AI's understanding of physical properties and the words humans use to describe actions. This kind of synergy will, in the long-term, yield robots with a human-like understanding of objects, forces, and tasks, achieved through embodied experience. Such robots will learn as children do, by experiencing the world. Machines that do that will be easier for ordinary people to understand and communicate with. They also may well require less data and computational power.

Another area of deep TII expertise that informs work in humanoid robotics is TII's Cryptography Research Center (CRC) and other centers focusing on secure systems. These contributions include protocols to protect data storage and transmission. This will be vital to prevent hacking and ensure data privacy in robots as they move around workspaces and homes. For instance, CRC's research into quantum-safe cryptography and AI frameworks aims to future-proof robotic systems against attacks from future quantum computers, ensuring long-term security for critical robotic deployments.

All of these component-focused research programs allow TII to concentrate on mastering foundational capabilities — sequentially or in parallel modules. The emphasis is on achieving robustness and reliability in one core function (for example, stable navigation in cluttered spaces) before integrating it with others. In this work, it is important to avoid duplicating research in one area that has already been done in another. So TII researchers avoid "bespoke," one-use software and hardware development. Instead, they prioritize components that can be used in multiple different devices and contexts. A perception system for a delivery robot, for example, should be usable in later, more sophisticated machines.



Real-World Integration

Robotics projects are often impressive in controlled laboratory settings. But humanoid robots must be able to work in the constantly changing and messier world of human beings and the spaces they inhabit. This is the source of TII's third humanoid-development principle – real world integration. To ensure that its parts-first, physical AI strategy will lead to useful humanoids, TII collaborates with industry partners and government entities to deploy simpler robotic systems in real operational environments – not just in labs.

The initial focus for deploying and testing TII's foundational robotic technologies (components destined for future humanoids) lies in sectors where automation can provide clear value and where the UAE has strategic interests. While some systems are not yet deployed at scale, they are being actively tested on-site in realistic operational environments across the country.

Advantages of Putting Robots in Real World Settings

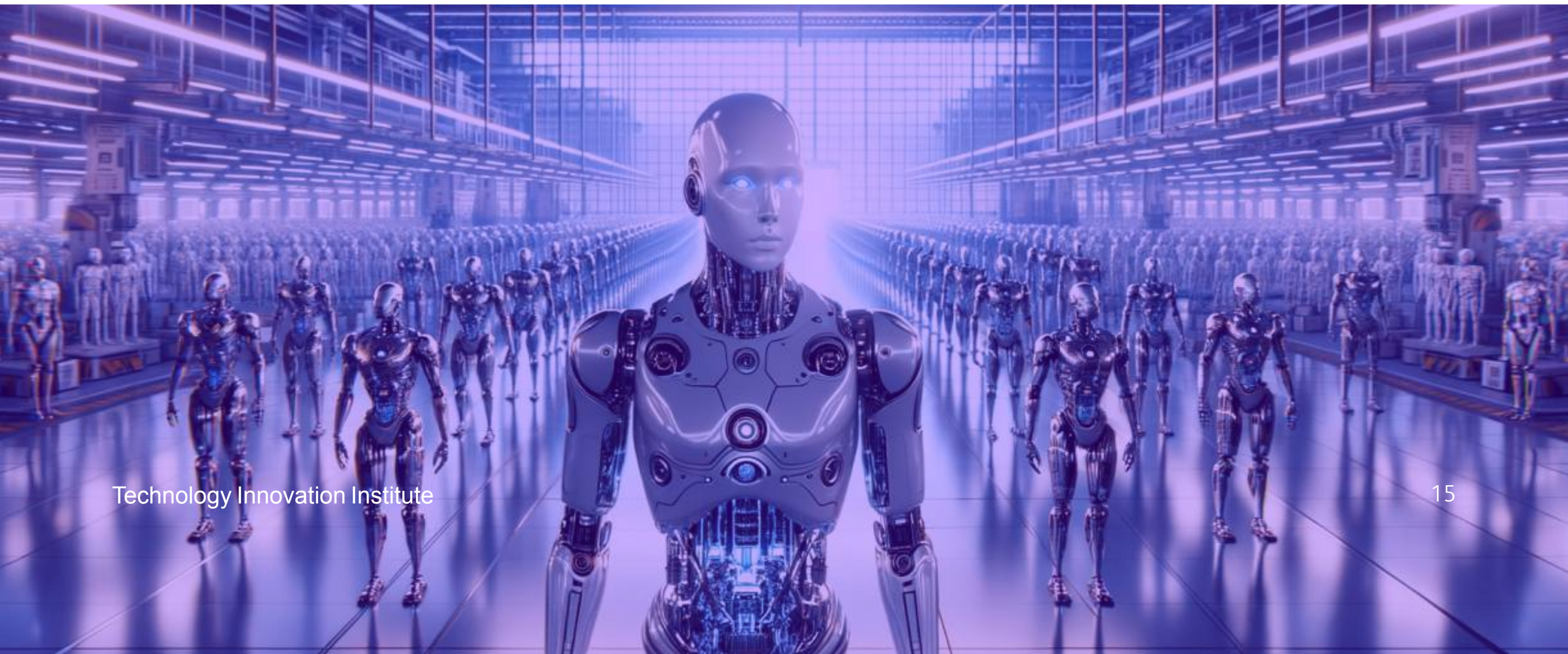
This approach offers invaluable advantages:

Real World Data Collection: Gathering data on performance, failure modes, and interaction challenges in authentic conditions, which is far more valuable than lab data.

Iterative Refinement: Continuously improving algorithms, hardware components, and software based on empirical feedback and operational requirements.

Cost-Effective Validation: Testing core technologies on less complex, lower-cost platforms before integrating them into a full humanoid reduces development risk and cost.

Early Value Demonstration: Delivering practical solutions using component technologies generates early successes, builds stakeholder confidence, and potentially creates revenue streams that can support further Research and Development.



Real-World Integration

Examples of TII Research Deployments

The initial focus for deploying and testing TII's foundational robotic technologies (components destined for future humanoids) lies in sectors where automation can provide clear value and where the UAE has strategic interests.

Robotic Food Assembly in Real World Kitchens

TII researchers are deploying robot arms in fast food restaurant kitchens, aiming to fully automate complex tasks like the preparing of a burger or a pizza. (Restaurants will be a significant opportunity for humanoid robots: Unlike other types of robot, humanoids don't require major alterations of a restaurant's kitchen and practices.) The TII approach in these workplaces combines traditional robotics methods (linking sensor data to motion planning and actions with new techniques. These newer methods include imitation learning (where robots learn by imitating humans or other robots) and "Visual Language Action" (VLA) models.

A VLA links visual data (what the robot sees) to instructions it was given in normal non-specialized language, in order to generate actions. The research uses TII's own VLA model, built with data collected by the robots themselves.

Deploying these tools in real robots in real restaurants allows TII researchers to evaluate and improve the products in a naturally quick-changing environment. After further refinement, these robot control systems will be ported into TII's humanoid robots.

Warehouse Packaging and Delivery Automation

In the warehouse domain, TII researchers are using robots to automate the packaging of groceries. This is a challenge for conventional robots because it involves an unpredictable series of items that vary in size, shape, weight and other traits. To overcome it, researchers again combine the standard components of a robot arm with VLA models. These models provide the robot with the information it needs about each item, so that it knows to handle an orange differently from a box of pasta, and can deal with surprise changes (like a torn bag).

By integrating Physical AI and other models with traditional motion planning, TII is creating systems capable of adapting to the dynamic and cluttered nature of warehouse environments. The perception system identifies and classifies items, while the robot formulates its policy for executing the necessary packaging steps. This system is currently deployed in a variety of robot forms, including mobile carts that deliver packed groceries to users in residential buildings, and a four-footed delivery robot designed to navigate villa complexes. All platforms are coordinated through a scalable fleet management system, allowing centralized control and intelligent routing across multiple types of robot. Each user can decide to use one robot, or multiple robots through a centralized control interface, and monitor their status and activity in real time.

Inspection and maintenance and security patrolling

Real-World Integration

Many industrial sites need continuous surveillance. For example, in an operational plant they continually check for potential anomalies in some gauges, the presence of unauthorized personnel or other problems. In a site under construction, surveillance continually assesses the progress of work. This already is one of the most common applications of robot dogs. Humanoids, like the quadrupeds, can climb stairs and go into spaces impossible for wheeled robots. But humanoids, being shaped like a person, can also easily merge in new areas built for humans without requiring modifying the environment to fit the machine.

Expanding Horizons: Advanced Future Applications Across More Industries

As TII integrates validated components into increasingly sophisticated humanoid platforms, the range of potential applications for robots will expand significantly, eventually including

High-Risk Industrial Tasks: Performing maintenance, inspection, or intervention in hazardous environments (e.g., energy sector infrastructure, chemical plants, disaster sites), leveraging humanoid dexterity and mobility while removing human risk.

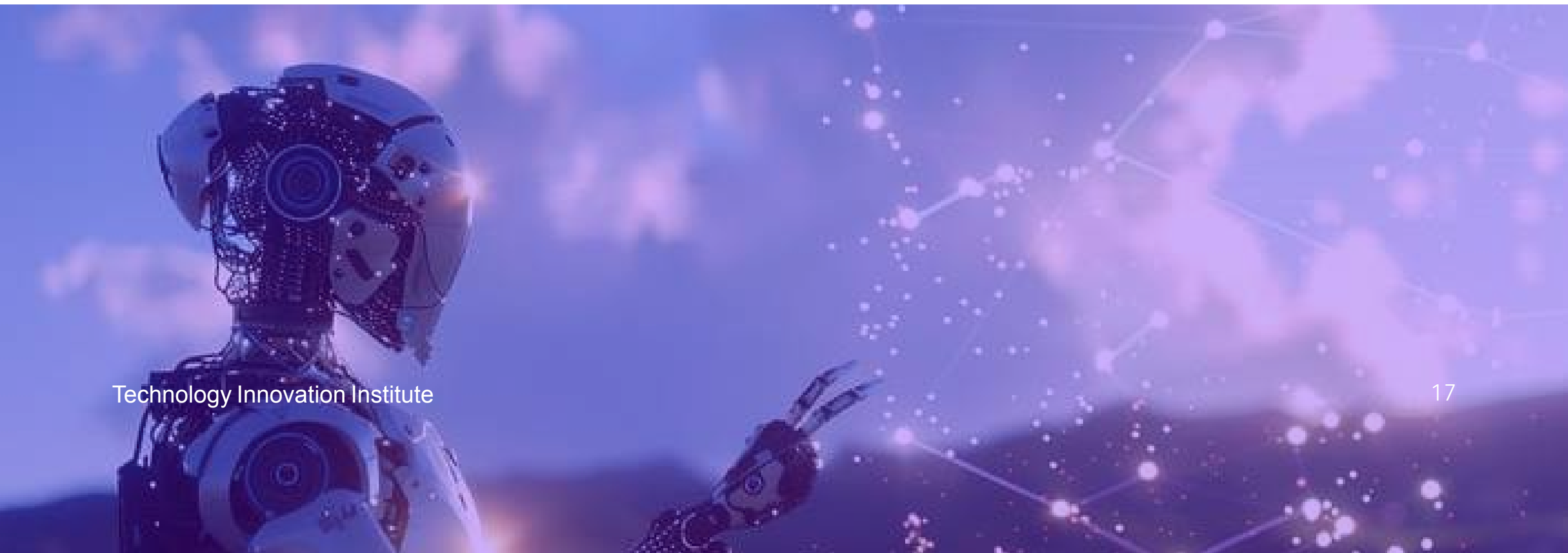
More Advanced Healthcare Assistance: Providing more complex support for patients in hospitals or homes (e.g., assistance with daily living activities, rehabilitation support), requiring advanced HRI, safety, and manipulation skills.

Specialized Agriculture: Performing delicate tasks like harvesting specific crops or monitoring plant health in vertical farms or traditional agriculture, requiring fine manipulation and perception.

Space Exploration and Operations: Assisting astronauts with tasks inside or outside spacecraft or habitats, leveraging the humanoid form to use human tools and interfaces in environments designed for humans. TII's broader research context provides potential links here.

Desert Navigation and Exploration: Developing robust locomotion and navigation capabilities suited for challenging desert terrains, relevant to the UAE's environment and potential applications in resource exploration or environmental monitoring.

Personalized Assistance and Education: Future possibilities include robots assisting in homes with chores or providing tailored educational interactions, requiring sophisticated HRI and adaptability.



Real-World Integration

Construction:

At construction sites, mobile robots can transport materials. monitor sites with cameras, lidar and other sensors and may also perform simple, repetitive tasks (e.g., basic assembly, surface finishing). This permits human workers to concentrate on higher-skill tasks, and affords researchers a chance to test robustness and navigation in challenging terrain.

Healthcare Logistics and Support:

Mobile robots already can transport medical supplies, equipment, or waste. They may soon also help monitor patients and help them to move. Deployments in hospitals and other healthcare facilities are promising test systems for safe human interaction, navigation in crowded spaces, and reliability.

Crucially, these future applications will directly benefit from the foundational strengths being developed today, such as advanced interaction capabilities, robust robotic perception systems, secure architectures, and the physically grounded intelligence derived from the "Physical AI" approach.

Designing for Trust and Acceptance:
The Role of Human-Robot Interaction Research

Another benefit of real world deployment is the ability to better understand how robots work with human beings. Therefore, HRI is a central research and design pillar of TII's humanoid program. As humanoids are deployed in homes, workplaces, hospitals and other human spaces, it is essential that the robots behave in ways that align with human expectations, reduce ambiguity, and foster trust. A sense of psychological safety is as crucial as physical safety, if robots are to be widely accepted and used.

Humans tend to naturally interpret movement, gaze, and the way the robot positions itself in space as cues to infer that robot's intent and abilities. Therefore, designers must ensure that robot behavior makes sense to humans, allowing people to understand and predict what the machine will do. People also have emotional responses to robots, attributing traits like friendliness, competence or menace to robot actions (even though those actions were not designed to evoke any feelings). Besides our instincts, humans are also shaped by expectations, biases, hopes and fears, often affected by cultural attitudes towards technology and popular culture, including movies, television shows and other media. And these impacts, which are elicited by even simple robots, are stronger for robots that resemble human beings. Even the most well-engineered robots could be rejected by people if their design neglects all these aspects of human-robot interaction (HRI).

The strategy follows these central principles:

Intuitive Interfaces:

TII seeks to create ways for people to interact with robots that feel natural and don't require special training. Instead of forcing people to learn complex commands or interfaces, TII interfaces depend on communication methods that come naturally to humans. This extends beyond spoken or written language. The research also includes other forms of communication that humans already understand instinctively:

- Hand gestures
- Where the robot looks
- How quickly or slowly the robot moves
- The robot's posture and stance
- How the robot expresses itself through movement.

Such non-verbal signals work well for human-robot communication because they are universal. People from different countries, speaking different languages, and of various ages and cultures, can all understand these non-verbal signals without instructions. This approach is especially helpful in situations where verbal communication might be difficult, like noisy environments or in a situation where workers speak different languages.

Designing for Trust and Acceptance:
The Role of Human-Robot Interaction Research

Predictable and Transparent Behaviors:

It is of paramount importance that humanoid robots act in ways that make sense to people. Therefore, robots need to do their work in ways that never violate the expectations of humans. People interacting with a humanoid robot should easily understand what the robot is doing, why it is doing it, and what it will do next. Hence, an important research goal for TII humanoids is the ability for robots to explain themselves in plain language.

Personalization and adaptation:

We envision robots adapting over time to users' preferences, communication styles, emotional responses, as well as cultural and contextual social norms. TII's approach integrates both short-term adaptation, long-term personalization and the capacity to generalize across multiple users' expectations to arrive at behavior acceptable to all. TII robots construct profiles of their human users, and update them in real time. These profiles include preferences, behavioral cues, patterns and interaction histories. As these profiles are constantly updated, each robot can refine its behavior with an individual, over repeated interactions.

Collaboration:

For humanoid robots to be truly effective in real-world environments, they must be able to collaborate with people – to work with humans rather simply for them. TII emphasizes the development of systems that support "shared agency" – control and decision-making that are shared between humans and robots. Such co-active systems would not only improve task performance in shared tasks and physical environments, but also strengthen user engagement, trust and confidence in robots' competence.

Safety, trust and ethics by Design:

At TII, safety is a principle embedded across all levels of system design. Physical safety is assured through systems that detect collision risks, and the design of actuators that respond to resistance by yielding, rather than pushing back with full force. TII robots are also equipped with a "kill switch" that provides a way for human to shut them down in event of danger. Psychological safety is assured through predictable, comprehensible and socially appropriate behavior.

Trust, though, is more than a sense of basic safety. It is fostered by ethical design choices: those that respect human autonomy, and preserve user privacy. By integrating these considerations into every robot's architecture and social behaviors, TII ensures that humanoid systems can be safely and confidently deployed in different environments such as homes, hospitals and public spaces.

Conclusion:
Towards a Future of Grounded Humanoid Intelligence

The journey towards truly capable, real world humanoid robots is complex and challenging, but the potential rewards – enhanced productivity, improved safety, augmented human capability, and new avenues for exploration – are immense. The Technology Innovation Institute is embarking on this journey with a clear vision and a distinct, pragmatic strategy: Physical AI, Multi-Part Development, and Real-World Integration, all informed by rigorous attention to Human-Robot Interaction.

TII's approach stands apart through its emphasis on those three key principles. By focusing on building foundational capabilities through practical applications within the UAE ecosystem before integrating them into a full humanoid platform, TII mitigates risks, accelerates learning, and ensures its innovations are grounded in tangible utility.

TII is uniquely positioned to make significant contributions to the field. Leveraging foundational strengths in robotics, AI, autonomous systems, perception, secure communications, and benefiting from the supportive innovation ecosystem of the UAE, TII has the resources, talent, and strategic environment necessary for success. The focus on physical interaction, robust software architecture, and human-robot interaction further differentiates TII's initiative.

TII recognizes that technological advancement must proceed hand-in-hand with ethical consideration and a commitment to societal benefit. TII's focus on security, safety, transparency, and understanding the societal implications of humanoid deployment underscores TII's dedication to responsible innovation. The goal is not simply to build advanced machines, but to develop trustworthy systems that integrate seamlessly and positively into human society.

TII's vision extends to a future where humans and robots collaborate effectively, augmenting each other's strengths to achieve common goals. The development of capable, reliable, and interactive humanoid robots is a critical step towards realizing this vision. Through its strategic, pragmatic, and learning-driven approach, the Technology Innovation Institute is poised to be a key player in shaping the evolution of humanoid robotics, driving towards a future where intelligent machines work alongside humans to tackle complex challenges and unlock new possibilities within the UAE and across the globe.

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