Dynamic Penetrative Trajectory Adaptation ⋆

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Abstract: DPTA is a conceptual framework where the LLM's world knowledge is leveraged to analyze low-level sensor feedback, enabling the dynamic selection and refinement of complex, pre-learned robot trajectories to achieve high dexterity and resilience in autonomous manipulation.

Keywords: LLM, robotic, Reenforcement Learning.

1. INTRODUCTION

interactive robots mission is a complex mission it need to nagvigate in complex and dynamic environment also need to fully flexable to planing the sequentially sub tasks. In order to achieve the goal we demo a method by utlize LLMs(large language model) and Reenforcement Learning. Our idea focuses on using an LLM's capacity for precise, short-horizon physical reasoning to dynamically select or modify the parameters of complex, learned robotic trajectories, effectively allowing the robot to autonomously execute tasks that previously required initial human intervention. The conceptual framework of Dynamic Penetrative Trajectory Adaptation (DPTA) represents a synthesis of three distinct advanced AI paradigms found in the sources: Penetrative AI (LLM sensor comprehension), Dynamic Movement Primitives (DMP) and Human-Robot Collaboration (HRC) for trajectory learning, and Robust Reinforcement Learning (RL) for policy optimization and action excution.

2. BACKGROUND

The complex nature of interactive robot missions, particularly those involving high-level language models (LLMs) or sophisticated reinforcement learning (RL), presents numerous challenges across planning, learning, perception, and execution.

2.1 Main challenges

Limitations in High-Level Planning and Trajectory Execution (LLMs) When LLMs are used for autonomous manipulation, they encounter issues related to generating and executing physical motions: • Inability to Handle Complex TrajectoriesLiu et al. (2024) (Feasibility Issues): The conventional approach of using LLMs to generate code for robot motion falters when dealing with complex trajectories. Tasks that require intricate trajectory planning and reasoning over environments, such as opening an oven door featuring a horizontal axis design or opening a cabinet with a press-pull structure, may be deemed infeasible when relying only on the basic motion library generated by the LLM.Liu et al. (2024) • Fragility of Prompt Design: The current design paradigm for using LLMs as controllers is fragile, meaning even minor alterations in the prompt can dramatically affect the performance.Wang et al. (2024) Designing a reliable prompt for robotic tasks is not yet well understood.

Executability Anomalies: Although generally high, the code generated by the LLM can occasionally generate subtasks without assigning corresponding motion functions, resulting in non-encodable and non-executable responses-Liu et al. (2024).

Issues Related to Perception and Grounding Successfully linking high-level instructions to the physical world introduces multiple errors: • Environmental Perception Errors and Error Accumulation: Real-world task success rates decrease due to error accumulation across sequential subtasks.Liu et al. (2024) Errors in environmental perception stem from inaccuracies in object detection models (like YOLOv5), such as bounding box inaccuracies, leading to slightly variable coordinates for target objects.Liu et al. (2024) These discrepancies can cause the errors to exceed the necessary margins for precise manipulation (e.g., placing an apple into an oven with minimal clearance).Liu et al. (2024) • Sensor Data Processing Limitations: LLMs, when used in a "penetrative" way to analyze digitized sensor signals (like sequences of ECG digits), exhibit lower efficiency in processing extensive sequences of digital data compared to traditional methods.Xu et al. (2024) The hallucination rates and Mean Absolute Errors (MAEs) for some LLMs escalate with the increase in window size of the input data, suggesting an inherent limitation in processing extensive lengths of digitized sequences.Xu et al. (2024) • Susceptibility to Deployment Noise: Policies trained in simulation, even when using modern techniques, may

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not be robust to real-world noise. For instance, a policy trained in simulation for pick-and-place was not robust to small errors in box position estimation (e.g., errors with a standard deviation of 1cm) when deployed on a physical robot.Andrychowicz et al. (2017)

Challenges in Low-Level Control

Controllability and Security Risks: Since LLM responses are probabilistic, there is no guarantee that the swarm will behave as intended. This also introduces new security vulnerabilities, as it needs to be studied if users or even other robots can reprogram robots through prompt injection attacks or if a malicious agent could send misleading information (Byzantine robot detection)Strobel et al. (2024)

2.2 Solution Overview: Dynamic Penetrative Trajectory Adaptation (DPTA)

In current LLM-based manipulation, environmental information is primarily derived visually (e.g., YOLOv5 for object position)Liu et al. (2024). However, fine-grained tasks often depend on non-visual physical feedback (e.g., force or torque required to open a tight hinge). In DPTA, the Penetrative AIXu et al. (2024) paradigm is employed to process digitized sensor signals** from the robot's end effector (e.g., force/torque sensors, joint current feedback)

LLM's task is not to determine a broad state (like "indoors/outdoors"), but to execute a real-time, micro-level physical classification of the object/environment state during the initial phase of interaction (e.g., the first 100 milliseconds of grasping a handle or pushing a button)Bhat et al. (2024).

Our prompt utilizes the procedural guidance and fuzzy logic methods demonstrated in the heart rate detection task.Xu et al. (2024) It contains a short sequence of raw numerical feedback (avoiding the token limit constraint associated with long digitized sequences) and instructs the LLM to classify the physical anomaly based on relative changes in the sequence.

Example Output: Based on the input torque sequence, the LLM reasoningLiu et al. (2024) determines the precise physical condition, such as "Horizontal-Axis Oven Door, stiff hinge" or "Press-Pull Cabinet, high friction."

2.3 Equations

Some words might be appropriate describing equation (1), if we had but time and space enough.

$$\frac{\partial F}{\partial t} = D\frac{\partial^2 F}{\partial x^2}. \tag{1}$$

See **?**, **?**, **?** and **?**.

Example. This equation goes far beyond the celebrated theorem ascribed to the great Pythagoras by his followers.

Theorem 1. The square of the length of the hypotenuse of a right triangle equals the sum of the squares of the lengths of the other two sides.

Proof. The square of the length of the hypotenuse of a right triangle equals the sum of the squares of the lengths of the other two sides.

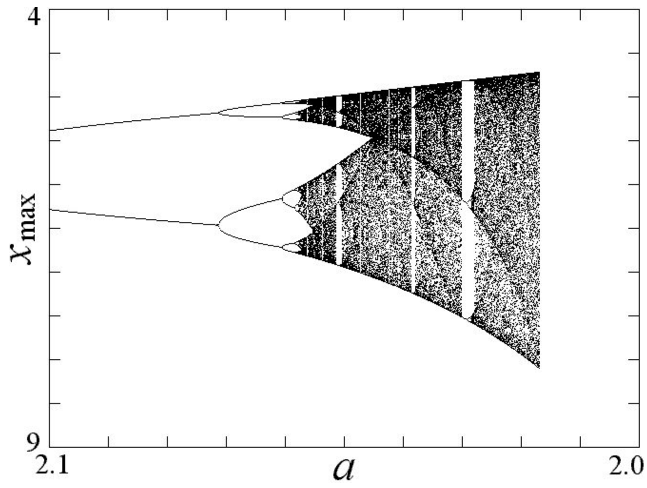

Fig. 1. Bifurcation: Plot of local maxima of x with damping a decreasing

Of course LaTeX manages equations through built-in macros. You may wish to use the `amstex` package for enhanced math capabilities.

2.4 Figures

To insert figures, use the `graphicx` package. Although other graphics packages can also be used, `graphicx` is simpler to use. See Fig. 1 for an example.

Figures must be centered, and have a caption at the bottom.

2.5 Tables

Tables must be centered and have a caption above them, numbered with Arabic numerals. See table 1 for an example.

Table 1. Margin settings

Page	Top	Bottom	Left/Right
First	3.5	2.5	1.5
Rest	2.5	2.5	1.5

2.6 Final Stage

Authors are expected to mind the margins diligently. Papers need to be stamped with event data and paginated for inclusion in the proceedings. If your manuscript bleeds into margins, you will be required to resubmit and delay the proceedings preparation in the process.

Page margins. See table 1 for the page margins specification. All dimensions are in *centimeters.*

2.7 PDF Creation

All fonts must be embedded/subsetted in the PDF file. Use one of the following tools to produce a good quality PDF file:

PDFLaTeX is a special version of LaTeX by Han The Thanh which produces PDF output directly using Type-1 fonts instead of the standard `dvi` file. It accepts figures in JPEG, PNG, and PDF formats, but not PostScript. Encapsulated PostScript figures can be converted to PDF with the `epstopdf` tool or with Adobe Acrobat Distiller.

Generating PDF from PostScript is the classical way of producing PDF files from LaTeX. The steps are:

(1) Produce a `dvi` file by running `latex` twice.
(2) Produce a PostScript (`ps`) file with `dvips`.
(3) Produce a PDF file with `ps2pdf` or Adobe Acrobat Distiller.

2.8 Copyright Form

IFAC will put in place an electronic copyright transfer system in due course. Please *do not* send copyright forms by mail or fax. More information on this will be made available on IFAC website.

3. UNITS

Use SI as primary units. Other units may be used as secondary units (in parentheses). This applies to papers in data storage. For example, write "15 Gb/cm^2 (100 Gb/in^2)". An exception is when English units are used as identifiers in trade, such as "3.5 in disk drive". Avoid combining SI and other units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity in an equation. The SI unit for magnetic field strength $\mathbf{H}$ is A/m. However, if you wish to use units of T, either refer to magnetic flux density $\mathbf{B}$ or magnetic field strength symbolized as $\mu_0\,\mathbf{H}$. Use the center dot to separate compound units, e.g., "A $\cdot$ m^2".

4. HELPFUL HINTS

4.1 Figures and Tables

Figure axis labels are often a source of confusion. Use words rather than symbols. As an example, write the quantity "Magnetization", or "Magnetization M", not just "M". Put units in parentheses. Do not label axes only with units. For example, write "Magnetization (A/m)" or "Magnetization (Am^{-1})", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

Multipliers can be especially confusing. Write "Magnetization (kA/m)" or "Magnetization (10^{3}A/m)". Do not write "Magnetization (A/m) $\times$ 1000" because the reader would not know whether the axis label means 16000 A/m or 0.016 A/m.

4.2 References

Use Harvard style references (see at the end of this document). With LaTeX, you can process an external bibliography database using `bibtex`, [1] or insert it directly into the reference section. Footnotes should be avoided as far as possible. Please note that the references at the end of this document are in the preferred referencing style. Papers that have not been published should be cited as "unpublished". Capitalize only the first word in a paper title, except for proper nouns and element symbols.

[1] In this case you will also need the `ifacconf.bst` file, which is part of the `ifaconf` package.

4.3 Abbreviations and Acronyms

Define abbreviations and acronyms the first time they are used in the text, even after they have already been defined in the abstract. Abbreviations such as IFAC, SI, ac, and dc do not have to be defined. Abbreviations that incorporate periods should not have spaces: write "C.N.R.S.", not "C. N. R. S." Do not use abbreviations in the title unless they are unavoidable (for example, "IFAC" in the title of this article).

4.4 Equations

Number equations consecutively with equation numbers in parentheses flush with the right margin, as in (1). To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Use parentheses to avoid ambiguities in denominators. Punctuate equations when they are part of a sentence, as in

$$\begin{aligned}\int\limits_0^{r_2} & F(r,\varphi)drd\varphi = [\sigma r_2/(2\mu_0)] \\ & \cdot \int\limits_0^{\inf} exp(-\lambda|z_j - z_i|)\lambda^{-1}J_1(\lambda r_2)J_0(\lambda r_i)d\lambda\end{aligned} \tag{2}$$

Be sure that the symbols in your equation have been defined before the equation appears or immediately following. Italicize symbols (T might refer to temperature, but T is the unit tesla). Refer to "(1)", not "Eq. (1)" or "equation (1)", except at the beginning of a sentence: "Equation (1) is ...".

4.5 Other Recommendations

Use one space after periods and colons. Hyphenate complex modifiers: "zero-field-cooled magnetization". Avoid dangling participles, such as, "Using (1), the potential was calculated" (it is not clear who or what used (1)). Write instead: "The potential was calculated by using (1)", or "Using (1), we calculated the potential".

A parenthetical statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.) Avoid contractions; for example, write "do not" instead of "don' t". The serial comma is preferred: "A, B, and C" instead of "A, B and C".

5. CONCLUSION

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

ACKNOWLEDGEMENTS

Place acknowledgments here.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work the author(s) used [NAME TOOL / SERVICE] in order to [REASON]. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

REFERENCES

Andrychowicz, M., Wolski, F., Ray, A., Schneider, J., Fong, R., Welinder, P., McGrew, B., Tobin, J., Pieter Abbeel, O., and Zaremba, W. (2017). Hindsight experience replay. *Advances in neural information processing systems*, 30.

Bhat, V., Kaypak, A.U., Krishnamurthy, P., Karri, R., and Khorrami, F. (2024). Grounding llms for robot task planning using closed-loop state feedback. *arXiv preprint arXiv:2402.08546*.

Liu, H., Zhu, Y., Kato, K., Tsukahara, A., Kondo, I., Aoyama, T., and Hasegawa, Y. (2024). Enhancing the llm-based robot manipulation through human-robot collaboration. *arXiv preprint arXiv:2406.14097*.

Strobel, V., Dorigo, M., and Fritz, M. (2024). Llm2swarm: robot swarms that responsively reason, plan, and collaborate through llms. *arXiv preprint arXiv:2410.11387*.

Wang, Y.J., Zhang, B., Chen, J., and Sreenath, K. (2024). Prompt a robot to walk with large language models. In *2024 IEEE 63rd Conference on Decision and Control (CDC)*, 1531–1538. IEEE.

Xu, H., Han, L., Yang, Q., Li, M., and Srivastava, M. (2024). Penetrative ai: Making llms comprehend the physical world. In *Proceedings of the 25th International Workshop on Mobile Computing Systems and Applications*, 1–7.

Appendix A. A SUMMARY OF LATIN GRAMMAR

Appendix B. SOME LATIN VOCABULARY