Poster Abstract: Towards Autonomous Utility-Aware Energy Management for Energy Harvesting Devices

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ABSTRACT

Energy-harvesting wireless sensors require energy management due to volatile energy sources. Existing energy managers lack adaptability to changing utility requirements or often rely on manually defined utility profiles. To address this, we study an autonomous energy manager that learns utility profiles dynamically, without the need for prior data. The new energy manager ensures that devices adapt to evolving utility needs, extending their operational capabilities in changing environments.

KEYWORDS

energy harvesting, adaptive sensing, internet of things

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1 INTRODUCTION

Energy-harvesting wireless sensor devices represent a significant advancement in sustainable technology. However, they introduce unique challenges, particularly in energy management. The intermittent nature of their energy sources, such as photovoltaic cells, means they can fail during periods of energy unavailability, severely limiting their forward progress albeit having capacitor to buffer energy. This unpredictability necessitates efficient energy management strategies. A primary concern is the reliance on manual tuning, which is often unfeasible for larger deployments where dynamic conditions can vary widely.

The majority of existing energy management (EM) planners [1–3] ensure energy-neutral operations and make a general assumption of constant energy consumption demand across all time slots. This one-size-fits-all approach often fails to capture the dynamic nature of real-world applications. Only a couple of recent planners [1, 2] recognize the importance of time-varying utility. But also these advanced planners come with a limitation: they require a user-defined utility (consumption) profile prior to deployment.

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2 AUTONOMOUS UTILITY LEARNING

In our research, we emphasize on the autonomous learning of user-defined utility. Instead of relying on pre-deployment utility profiles, our approach dynamically learns these profiles as they evolve over time. This adaptability ensures that system can respond effectively to changing conditions, allowing for strategic energy allocation to high utility slots, particularly during periods of reduced energy availability. This adaptability enhances the overall effectiveness of energy management planners.

For our study, we employ the application of person counting within the realm of batteryless devices, employing an EM planner customized for our specific case study. This application parallels the use of tinyML in devices for intelligent environmental monitoring, where it continually detects relevant elements over time. We then proceed to explore the feasibility region. *Feasibility configuration region* refers to configurations where application goals are met, specifically maintaining missed detections below 25%. We established this region by simulating 35 distinct configurations, combining different solar intakes and capacitor sizes. Our goal is not only to determine the feasible configuration range for our application but also to devise EM strategies that expand this region.

3 PROPOSED ENERGY MANAGER: DS+

Our proposed energy manager DS+, builds upon the foundation of the Depletion Safe EM [3], which employs a binary search algorithm to determine the optimal current for sustained device operation. While the DS method uses binary search, our system refines this technique to account for time-varying consumption based on learned application demands, such as increased person counts to maximize the application goal. It utilizes the multi-armed bandit Upper Confidence Bound approach, to learn utility profile without any prior data while keeping balance of exploration and exploitation of time-slots under energy constraint. This strategy prioritizes energy allocation during high detection periods, minimizing it during low detection phases to maximize the application goal but also dynamically adapts to application outputs over the time.

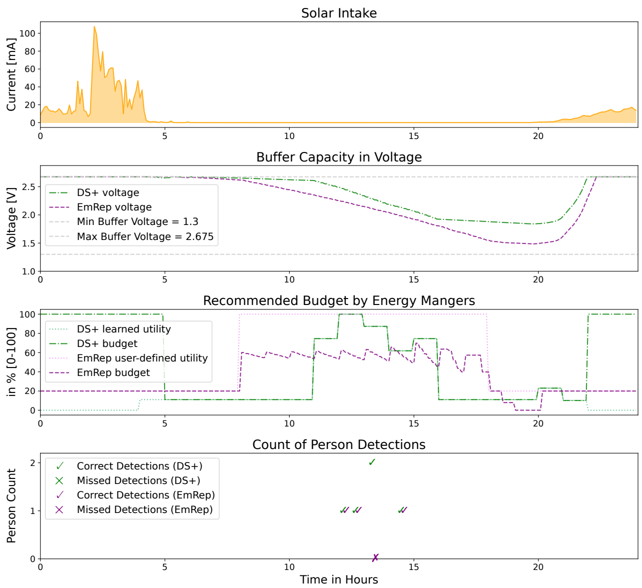

Figure 1: DS+ allocates more resources to slots where there's a higher learned likelihood of person presence.

Therefore, we refined the utility definition to be dynamic, changing with time rather than remaining static. This approach prioritizes the allocation of more resources to high-relevance slots. Moreover, when resources are abundant, we enhance allocation to other slots such as resources to high-relevance slots remain unaffected.

Figure 1 shows DS+ allocating more energy during slots with a higher learned likelihood of person presence and allocates less to other slots. Furthermore, DS+ even allocates more resources in contrast with the learned utility profile, particularly when resources are abundant during high energy harvesting periods. This results DS+ achieving a higher rate of person detection as compared to other energy manager to fulfill the application's primary objective.

4 PRELIMINARY RESULTS

For analysis, we compare our DS+ with state-of-the-art recent energy manager *EmRep*, which account for user defined time-varying utility prior to deployment. The comparative energy manager was provided with a pre-defined utility profile, with high utility requirement from 8 am to 5 pm. Our evaluation criteria included measuring missed persons and device failures (excluded here for brevity), providing a comprehensive understanding of each EM's effectiveness. In our experiments, we configured the energy managers to plan for a 24-hour horizon, utilizing an ideal energy harvesting predictor. These experiments were conducted over a duration of 80 days (we shifted solar intake by 12 hours to study challenging scenarios of misalignment with utility). Within this context, we conducted experiments involving varying capacitor sizes and solar intake levels. Our initial observations are encouraging. Our DS+ autonomously learns the utility profile without reliance on prior data yet extends the feasibility region in contrast to its peers. This feasibility region is characterized by having less than 25% missed detections, as illustrated in Figure 2.

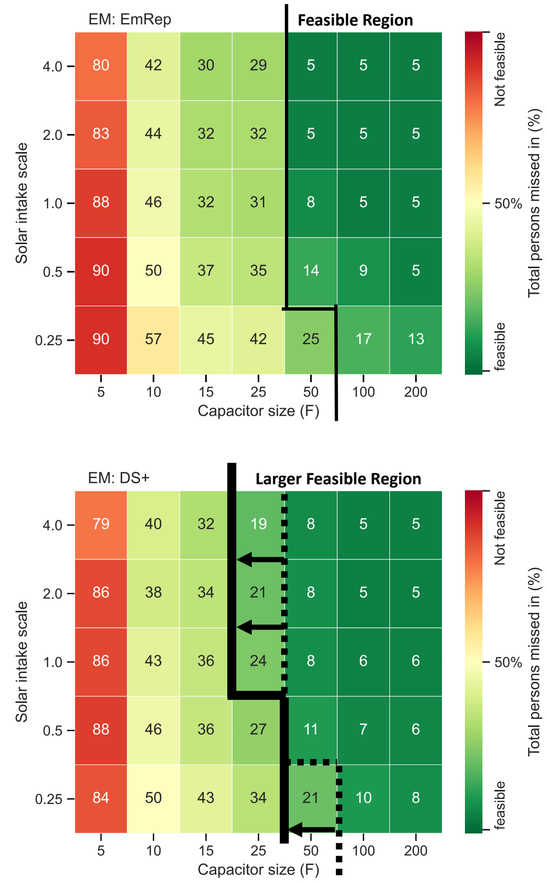

Figure 2: Expansion of feasible configuration region: Person Missed Rates across Capacitor Sizes & Solar Intakes. Feasible regions highlight < 25% missed detections.

5 CONCLUSION

Our proposed energy manager autonomously learns user-defined utility profiles, eliminating the need for prior defining utility-profile before deployment. Our findings demonstrate that our proposed energy manager not only learns without any prior data but also improves the feasible configuration region compared to current state-of-the-art. In the future, we will extend this work by analyzing energy metrics, and refine our energy manager to better allocate the available energy and conduct comprehensive comparisons with other existing energy management solutions.

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