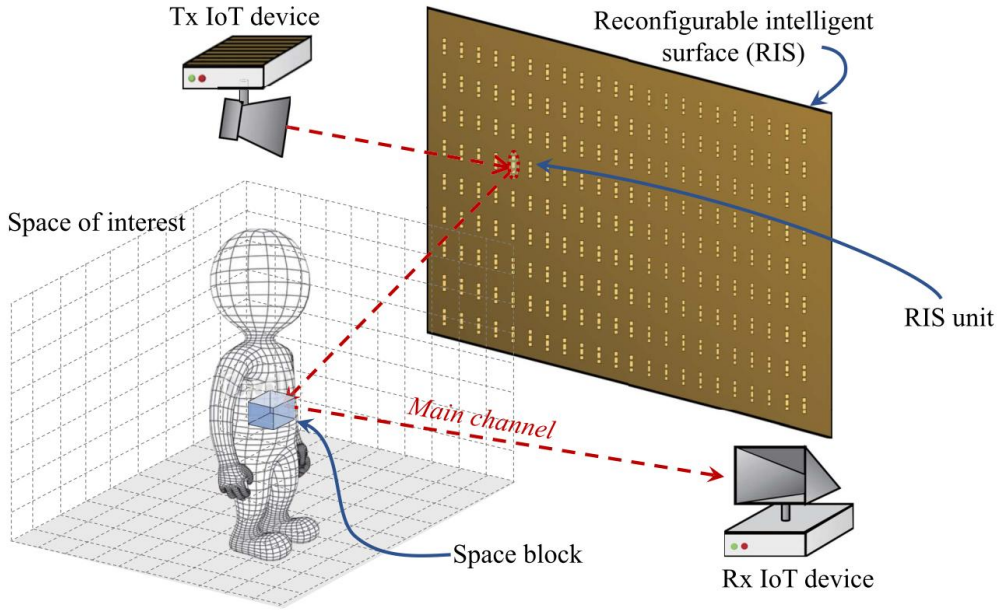
Reconfigurable Intelligent Surface Based RF Sensing Design, Optimization, and Implementation



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Reconfigurable Intelligent Surface Based RF Sensing: Design, Optimization, and Implementation

IF 17.2 SCIE JCR Q1 计算机科学1区 Top EI

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Abstract:
Using radio-frequency (RF) sensing techniques for human posture recognition has attracted growing interest due to its advantages of pervasiveness, contact-free observation, and privacy protection. Conventional RF sensing techniques are constrained by their radio environments, which limit the number of transmission channels to carry multi-dimensional information about human postures. Instead of passively adapting to the environment, in this paper, we design an RF sensing system for posture recognition based on reconfigurable intelligent surfaces (RISs). The proposed system can actively customize the environments to provide desirable propagation properties and diverse transmission channels. However, achieving high recognition accuracy requires the optimization of RIS configuration, which is a challenging problem. To tackle this challenge, we formulate the optimization problem, decompose it into two subproblems, and propose algorithms to solve them. Based on the developed algorithms, we implement the system and carry out practical experiments. Both simulation and experimental results verify the effectiveness of the designed algorithms and system. Compared to the random configuration and non-configurable environment cases, the designed system can greatly improve the recognition accuracy.

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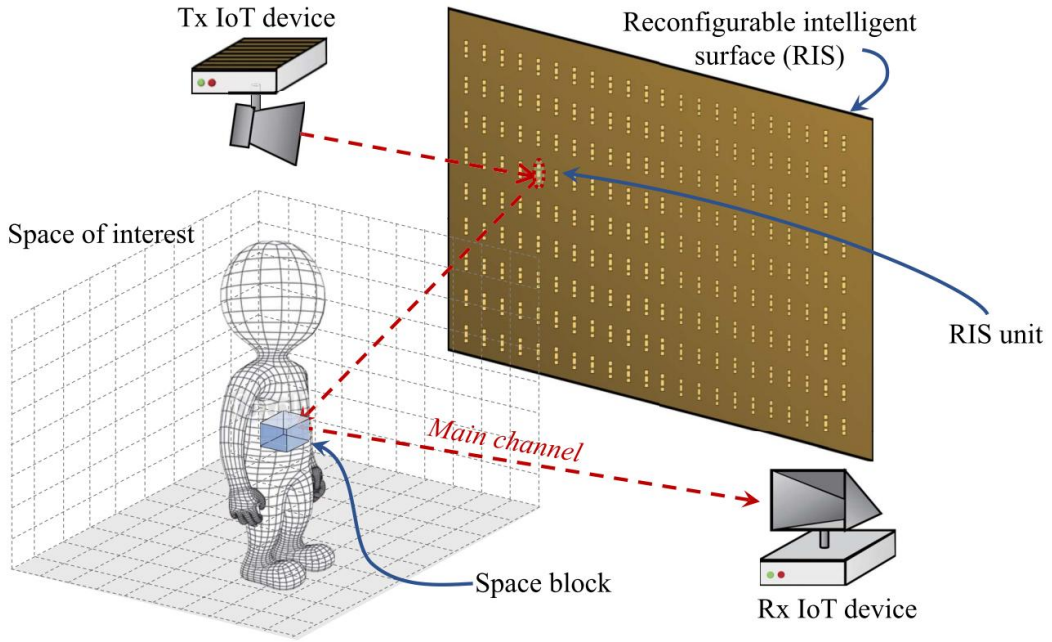
[1] J. Hu *et al.*, "Reconfigurable Intelligent Surface Based RF Sensing: Design, Optimization, and Implementation," in *IEEE Journal on Selected Areas in Communications*, vol. 38, no. 11, pp. 2700-2716, Nov. 2020

介绍框架

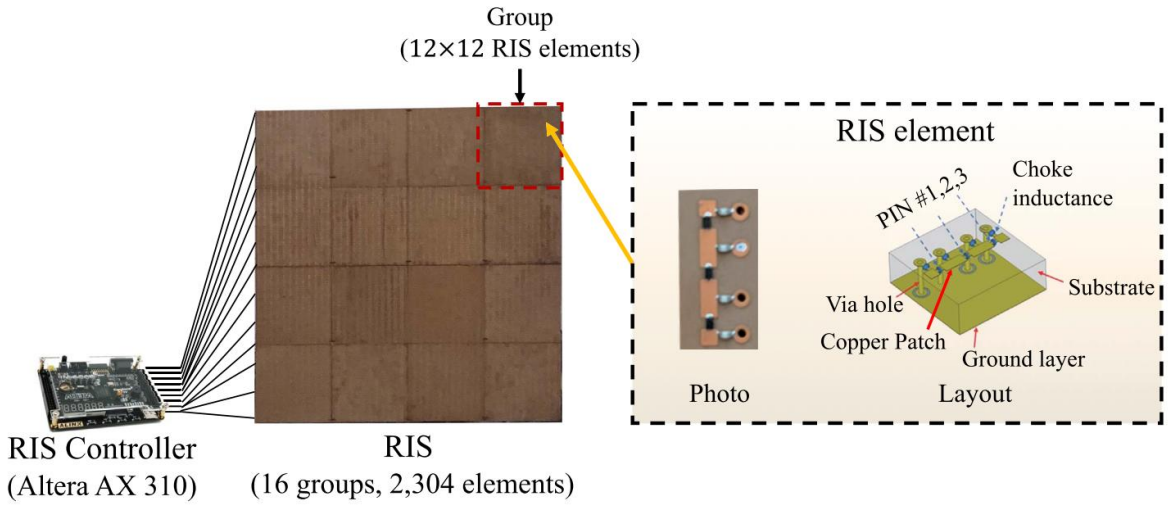
- 背景/简要介绍
- 研究方法
- 实验结果
- 总结



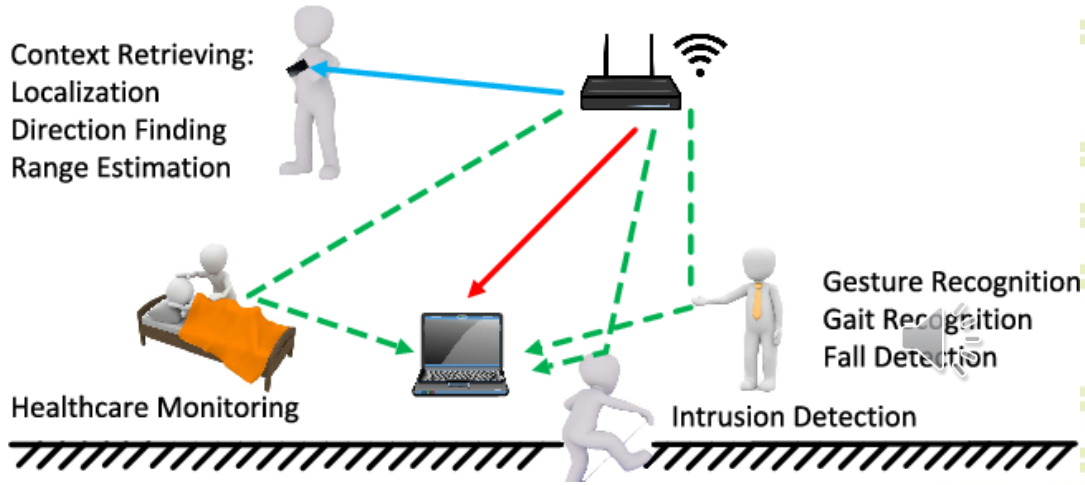
智能反射表面辅助的无线感知

- 什么是智能反射表面?
  - 一个由许多可重构单元组成的表面。
  - 使不可控的散射路径变得可控和可测量。
  - 在节点数量有限的情况下引入额外的无线链路。

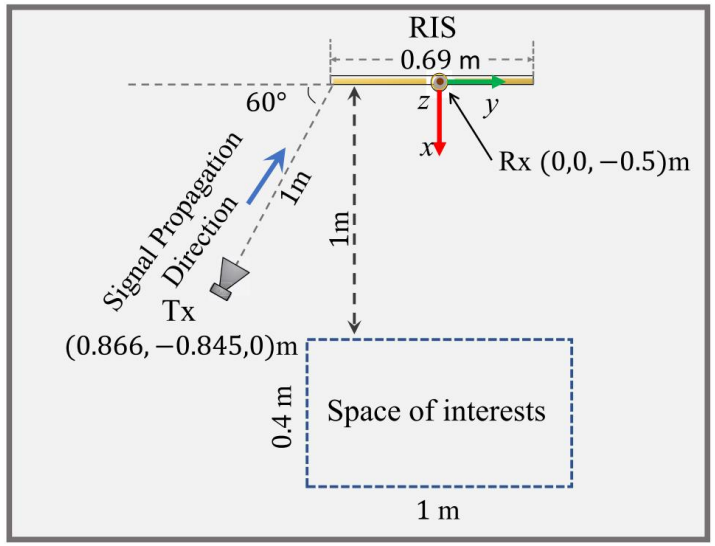
  → 对无线感知有很大的增益



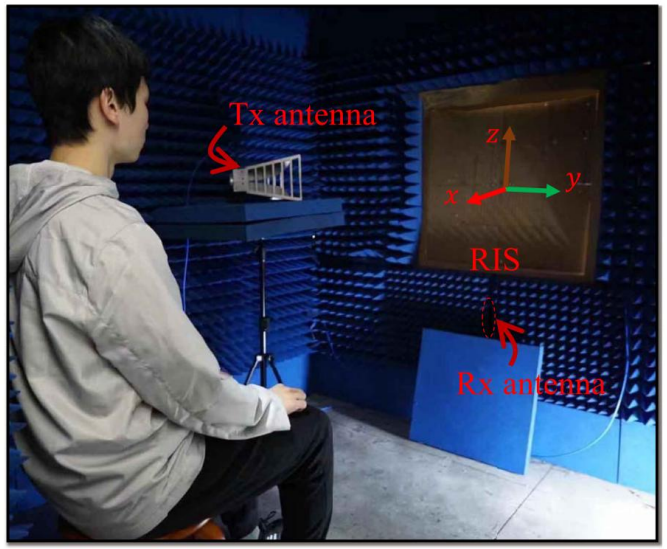
- 什么是无线感知?
  - 通过收集无线信号来感知环境中的变化与活动。
  - 定位 (localization) /姿势识别 (gesture recognition)



智能反射表面辅助的无线感知



(a)



(b)

实验相关参数

- 一对收发天线
- 中心频率
  - 3.198 GHz （单频点）
- 2304个智能反射表面单元
  - （0.69 m ≈ 7.4 个波长）
- 智能反射表面单元状态
  - 4种 $(45°, 135°, 225°, 315°)$
- 四种姿势
  - 站立/坐下/弯腰/卧倒
- 数据收集时间
  - 10帧 (3秒)
- 置信度
  - $> 90\%$

智能反射表面辅助的无线感知

- 接收信号模型

$$\boldsymbol{y} = h_d \cdot P_t \cdot \boldsymbol{x} + P_t \cdot \boldsymbol{x} \cdot \boldsymbol{T}\boldsymbol{A}\boldsymbol{\eta} + h_{\mathrm{rl}} \cdot P_t \cdot \boldsymbol{x} + \bar{\boldsymbol{\sigma}}. \quad (5)$$

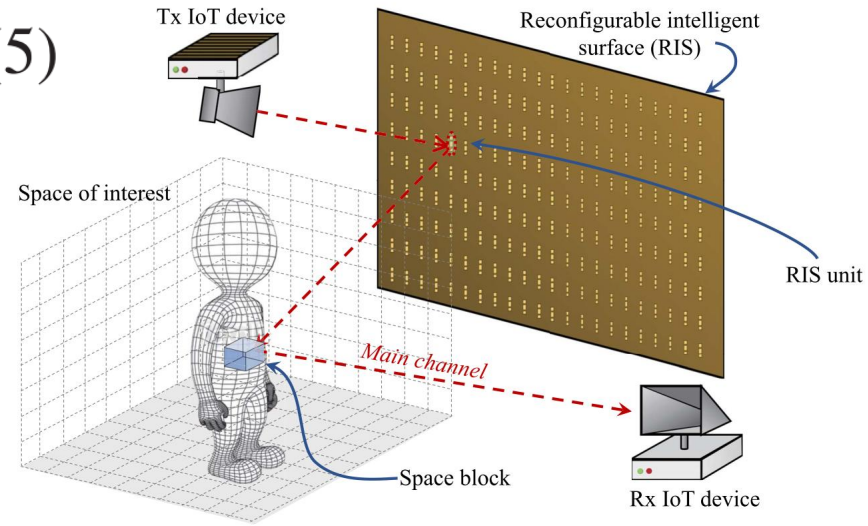
噪声

接收信号 (10×1)

直连信道

智能反射表面信道

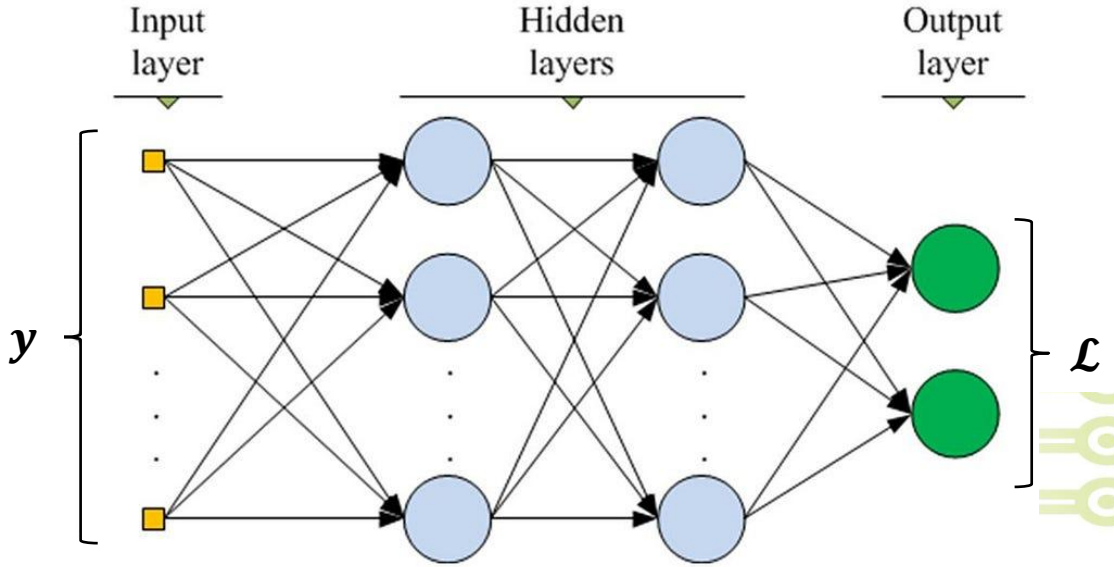
环境散射信道



- 感知功能实现
  - 深度神经网络姿势识别 （分类器/classifier）
  - 智能反射表面状态设置 (最小化相干性测度优化/mutual coherence minimization)

智能反射表面辅助的无线感知

- 姿势识别
  - 用深度神经网络做分类器
    - 输入：接收信号
    - 输出：判断函数 $\mathcal{L}(\boldsymbol{y}) \in \mathbb{R}^{4\times 1}$，每个元素代表对应对应姿势的概率 ([1,0,0,0]即代表是站着)。



- 智能反射表面状态设置

$$\mu(\boldsymbol{\Gamma}) = \frac{1}{M(M-1)} \cdot \sum_{m,m' \in [1,M], m \neq m'} \frac{|\boldsymbol{\gamma}_m^T \boldsymbol{\gamma}_{m'}|}{\|\boldsymbol{\gamma}_m\|_2 \cdot \|\boldsymbol{\gamma}_{m'}\|_2} \quad (21)$$

→ 压缩感知常用指标，越小代表获取的信息量越大

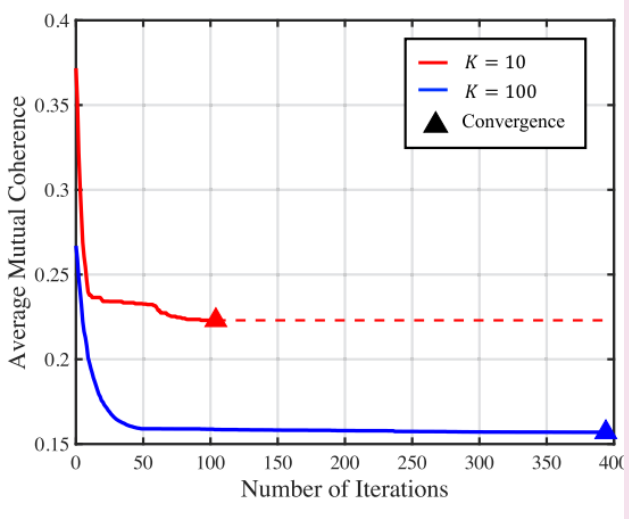
  - 参考了[2]中的非凸优化框架进行优化

[2] R. Obermeier and J. A. Martinez-Lorenzo, "Sensing Matrix Design via Mutual Coherence Minimization for Electromagnetic Compressive Imaging Applications," in *IEEE Transactions on Computational Imaging*, vol. 3, no. 2, pp. 217-229, June 2017

智能反射表面辅助的无线感知

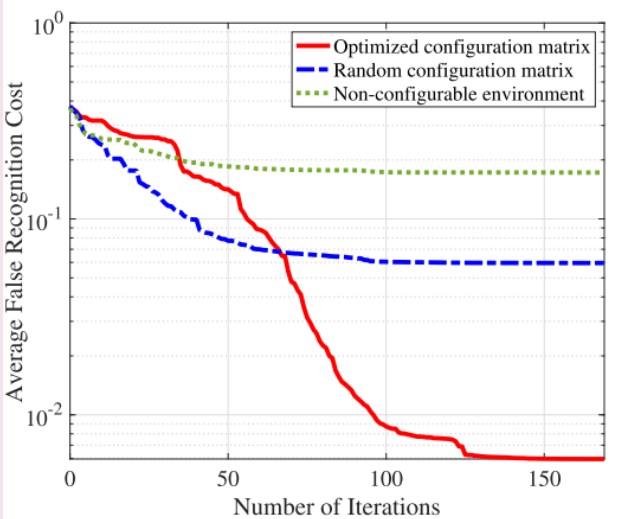
- 实验结果

1



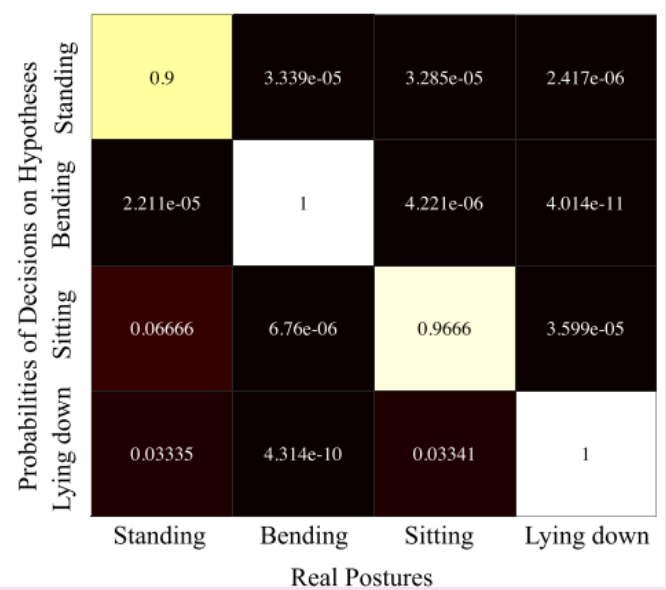
- 优化智能反射表面单元的状态以获得更多信息

2



- 训练神经网络

3



- 达到90%以上的置信度

智能反射表面辅助的无线感知

- 总结
  - 无线领域比较早期的智能反射表面辅助无线感知的工作
  - 机器学习做姿势识别，优化方法调整智能反射表面单元的状态

MetaLocalization: Reconfigurable Intelligent Surface Aided Multi-User Wireless Indoor Localization IF 10.7 SCIE JCR Q1 计算机科学1区 Top EI 2021 Cited 168

Haobo Zhang; Hongliang Zhang; Boya Di; Kaigui Bian; Zhu Han; Lingyang Song

IEEE Transactions on Wireless Communications

Year: 2021 | Volume: 20, Issue: 12 | Journal Article | Publisher: IEEE

Cited by: Papers (168)

MetaSensing: Intelligent Metasurface Assisted RF 3D Sensing by Deep Reinforcement Learning IF 17.2 SCIE JCR Q1 计算机科学1区 Top EI 2021 Cited 57

Jingzhi Hu; Hongliang Zhang; Kaigui Bian; Marco Di Renzo; Zhu Han; Lingyang Song

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Year: 2021 | Volume: 39, Issue: 7 | Journal Article | Publisher: IEEE

Cited by: Papers (57)