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Desenho e Desenvolvimento de um IMS Inteligente para Objectos Perdidos

Design and Development of an Intelligent IMS for Lost Items

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Design and Development of an Intelligent IMS for Lost Items

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia Informática, realizada sob a orientação científica do Doutor Eurico Farinha Pedrosa, Professor associado do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro, do Doutor Mario Luís Pinto Antunes, Professor associado do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro.

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acknowledgement of use of AI tools

Recognition of the use of generative Artificial Intelligence technologies and tools, software and other support tools.

I acknowledge the use of Grammarly (Grammarly, https://www.grammarly.com/) to improve and correct some sentences and paragraphs, pontuation and vocabulary. I acknowledge the use of ChatGPT-3.5 to improve the overall deliver of this Dissertation document.

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Glossary

AI Artificial Intelligence

IMS Inventory Management System

LF Lost-And-Found

LFS Lost-And-Found System

LLM Large Language Model

NLP Natural Language Processing

RFID Radio-Frequency Identification

QR Quick Response

CHAPTER 1

Introduction

"We never discover the value of things till we have lost them"
- Dinah Maria Craik, A Life For A Life (1859)

1.1 Context

The loss of personal items is a common situation that affects individuals in various contexts, from public spaces such as airports, universities and shopping centres [1], [2] to private institutions such as schools, companies and factories. On average, people misplace or completely lose up to nine items each week, with common culprits including mobile phones, keys, and sunglasses [3]. This distraction costs individuals from 15 to 50 minutes each day spent searching for these misplaced items [3], [4]. Over an average of 60 years of stated adult life, that implies approximately at least a total of 3680 hours (153,3 days) and 200000 items misplaced or wholly lost [5]. Adding to this issue, studies have revealed that the time spent searching for lost items can lead to financial losses that feel akin to literally throwing money away. The cumulative effect of these lost hours not only frustrates individuals but also impacts their financial well-being, a stark reminder of how daily distractions can drain both time and resources. These effects, when aggregated over long periods, also have alarming outcomes. The same studies also reveal a staggering annual waste of approximately $177 billion dollars [6] due to time spent searching for lost or misplaced items [5], which represents a figure that highlights a significant drain on productivity.

Traditionally, manually managing lost property has long been plagued by inefficiencies that disadvantage its corresponding stakeholders, i.e. the administrators and the individuals, both seeking to deliver and recover the lost belongings [7]. In most cases, the process relies heavily on manual efforts, requiring staff to record, store and track items using rudimentary tools such as paper records or basic spreadsheets. Others resort to simple and outdated Inventory Management System (IMS) that are not designed to handle the complexities of lost property management [8]. This labour-intensive approach is time-consuming and prone to human error, leading to lost items, inaccurate records and miscommunication between departments or stakeholders [7], [8]. Additionally, most of the designated staff responsible for handling these tasks is rarely compensated or formally recognised for this additional responsibility. These employees are typically expected to manage lost items alongside their regular workload without extra pay, training, or resources [8]. They are tasked with organising found objects, responding to enquiries and ensuring that the rightful owners are identified, often with little or no support from automated or systematic processes that divert attention from their core responsibilities and also foster frustration as they navigate an unsustainable workflow.

On the other hand, individuals searching for lost objects face significant challenges. The lack of a standardised or intuitive system means they have to rely on guesswork or luck to recover their belongings. The stress is even more significant when they do not know where to start their search or whether their lost object has even been found. The so-called "lost-and-found" effect is described by Garling et al. [9], explaining the stressful mental process of over-valuing and prioritising the recovery of a missing item.

The absence of transparent communication channels [8] or efficient recovery mechanisms further enhances this effect. Complementing the ineffectiveness, the risks associated with poorly managed lost items are substantial. Without secure processes, lost objects are vulnerable to theft or unauthorised access [10]. Identity forgery becomes a tangible threat when personal or sensitive belongings, such as identification documents or electronic devices, fall into the wrong hands [11]. In addition, the public disclosure of personal information associated with lost property has become a concern that has not yet been the subject of a standardised solution [11]. Furthermore, mismanagement can lead to legal complications, especially if disputes arise over lost objects that are improperly registered or returned to the wrong person. A prevalent issue with lost property platforms is the failure to establish a robust sense of trust among users [11]. Specifically, there is often a lack of reliable assurance between the owner of the lost item and the finder. This vulnerability can lead to dishonest behaviour, including fraudulent claims or requests.

From an organisational point of view, even though some institutions provide designated Lost-And-Found (LF) collection points [10], they also run the risk of damaging their reputation, potentially being held accountable and damaging relations with the communities they serve.

In a world where technology effortlessly facilitates online information retrieval, it is striking that we lack effective technological solutions for locating our physical belongings. This discrepancy highlights a critical gap in our everyday lives, underscoring the urgent need for innovative tools that can help us find our lost possessions efficiently.

1.2 Motivation

Since managing lost objects still represents a common challenge, creating more efficient systems to solve this problem can ease the burden among users and the community. With more efficient lost property information systems, manual processes that are currently riddled with inefficiencies, such as time-consuming workflows, human error and a lack of transparent communication channels, can be completely redesigned. Institutions can not only optimise recovery processes but also strengthen their commitment to user satisfaction, thus improving community relations and institutional reputation.

Emerging technologies such as Artificial Intelligence (AI), Natural Language Processing (NLP) and the increasing training and use of Large Language Model (LLM) offer unprecedented opportunities to address these challenges. AI can facilitate the identification and categorisation of lost objects, while NLP enables the use of users' interactions, such as searches and conversations, to extract relevant data [3]. In recent years, the advent of deep learning has revolutionised the performance of various visual tasks, leading to significant advancements in areas such as image classification [12]. These improvements are not limited to mere accuracy; they encompass enhanced efficiency in processing large datasets, the ability to recognise intricate patterns, and the capability to generalise across diverse scenarios. This thesis is motivated by the potential of these technologies to innovate in an area that remains underexplored, aiming to add to the lost object management into an efficient, secure and user-friendly experience. The integration of these technologies can redefine the standards of lost object recovery and management, resolving inefficiencies and building trust among stakeholders. Beyond merely improving operational processes, a reimagined system for managing lost property must also emphasise community integration. By leveraging technologies to enable direct communication between finders and owners, supported by platforms for community-based reporting, the solution can minimise reliance on intermediaries and streamline the recovery process. The community-oriented approach proposed by Guinard et al. [8] not only fosters trust among stakeholders but also encourages a culture of shared responsibility and collaboration, empowering users to take an active role in solving lost-and-found challenges.

A well-designed lost property management system has the potential to extend its impact far beyond the immediate issue of misplaced belongings. By addressing the inefficiencies inherent in traditional processes and adopting a community-driven, technologically sophisticated approach, the proposed solution could serve as a model for innovation in related domains, offering a framework for reducing theft, enhancing data privacy, and fostering transparency, which can, in turn, bolster trust. Moreover, such a system represents a tangible demonstration of how intelligent technologies can address real-world problems, ultimately contributing to a more connected, efficient, and equitable society. In this way, solving the problem of lost property management not only resolves a long-standing challenge but also sets a precedent for the transformative power of technological solutions.

1.3 Objectives

This research seeks to establish a secure and straightforward framework for addressing the inefficiencies in the management of lost property by defining specific and measurable objectives.A primary goal is to design and develop an IMS by exploring the application and capabilities of AI and NLP/LLM for automating the identification, categorisation, and recommendation of lost items, aiming to reduce manual workload and effectively complete the LF cycle of items. Another objective is to prioritise usability by ensuring that the proposed solution accommodates individuals with varying levels of technological proficiency, which involves examining design strategies that promote accessibility and simplify interactions, fostering a more inclusive approach.Encouraging community engagement is also a key focus, with an emphasis on fostering direct communication between users to strengthen collaboration and reduce dependency on intermediaries.This engagement indicates that the level of user interactions will highly modify the user experience.

The research aims to employ iterative testing and validation in both controlled and real-world settings. This includes evaluating the system's performance, usability, and scalability under diverse conditions. This implies the need to implement monitoring and observability methods to generate actionable insights, enabling continuous improvement of the solution.

The proposed research can be conducted in four key stages, which align with a logical progression from understanding the problem to delivering a robust, focusing on different aspects of design and development.

1. Study of the State-of-the-Art: Review existing i) on-production solutions, ii) available and recommended technologies, iii) best practices and optimal approaches and iv) challenges.
2. Design the structure of the system by defining its architecture, features and workflows.
3. Create the main system components, including all the planned features.
4. Test the system in a real and controlled environment.
5. Finalise and document the results for academic and practical use.

1.4 Dissertation Outline

This dissertation is structured into multiple chapters, each building upon the previous to provide a comprehensive understanding of the project and its outcomes. The document begins with an introductory chapter, Chapter 1, that offers background information, including the core problem being addressed, the motivation for this research, and the objectives associated with the proposed solution.

Following this, Chapter 2 examines the state of the art by reviewing the current literature and relevant technologies and on-production solutions. This chapter explores topics such as ...

Chapter 3 ...

Chapter 4 ...

In Chapter 5, ...

Finally, Chapter 6 will conclude the dissertation by summarizing the key outcomes and contributions of this work to the field.

CHAPTER 2

State of Art

2.1 Manually Managing Lost-And-Found Items

2.1.1 Traditional Lost-And-Found Systems

Traditional Lost-And-Found System (LFS) have been integral to managing misplaced belongings across various settings. These systems typically relied on manual processes to log and manage items, sometimes papers or books and, in a few cases, spreadsheets [13]. The fundamental components included physical logs, where details of found items - such as descriptions, location, and date of discovery - were recorded by staff or custodians.

Often, the responsibility of maintaining these records fell to a designated individual or department. Items were categorised and stored in a secure area, with the hope that owners would reclaim them. Matching found items to reported losses was a manual process, requiring significant time and effort [13]. Descriptions provided by claimants were cross-referenced with recorded details to determine ownership. In some cases, rudimentary tagging systems were used to label items, aiding the identification process.

In environments like universities or corporate campuses, basic digital tools such as spreadsheets were usually introduced to track items. However, the overall workflow remained heavily dependent on manual oversight. Community bulletin boards, notices, or word-of-mouth were also standard methods to inform individuals about found items.

Despite their simplicity, these systems played a critical role in facilitating the return of lost belongings in the pre-digital era [14]. They fostered a sense of trust and collaboration within communities, relying on the goodwill and honesty of both finders and administrators. The traditional systems established the groundwork for modern approaches, providing valuable insights into the challenges and requirements of effective lost-and-found management.

Despite the previously detailed inefficiencies of such systems, there are still those who would find these manual workflows to be more trustworthy. For some, the human element brings a level of accountability and understanding that automated systems cannot replicate. Manual processes allow for subjective judgment, which can be beneficial in complex scenarios where nuance is required. The tactile nature of handling paper documents or physical records fosters a sense of security and reliability. Moreover, people who have had negative experiences with technology might prefer traditional methods, viewing them as more stable and less prone to glitches or failures.

2.1.2 Obstacles in Traditional Systems

While traditional LFS have historically served their purpose in smaller or less demanding contexts, they face significant challenges when scaled to handle larger volumes of items or more complex environments [14]. The scalability of such systems is inherently constrained by their reliance on manual processes and both limited technological integration and automation.

A key obstacle is the dependency on human effort for recording, categorising, and matching items. As the number of lost items increases, so does the burden on staff, leading to delays, errors, and inefficiencies. In high-traffic environments, the sheer volume of items can quickly overwhelm even the most organised traditional systems. Without automation, processing and resolving claims becomes a time-intensive task, reducing the workflow's overall effectiveness.

Another barrier to scaling is the lack of centralised data management. In traditional systems, records are often siloed, with each location or department maintaining its logs. Especially in larger organisations or distributed campuses, the absence of a unified database also impedes efficient reporting and analysis of trends, such as identifying frequent loss locations or categories of items.

Communication between stakeholders presents further challenges. Traditional systems often lack robust mechanisms for notifying individuals about found items or updating claimants on the status of their reports, resulting in inefficiencies and frustrations, particularly in large-scale operations where the number of inquiries can be substantial.

Finally, the security of manual systems poses significant concerns. As the volume of items increases, the risk of theft, loss, or unauthorised access also rises. Inadequate labelling and verification processes can lead to disputes or errors in returning items to their rightful owners, further eroding trust in the system.

These obstacles highlight traditional systems' limitations in adapting to the demands of modern LF management. While effective in smaller, community-focused settings, their scalability issues underscore the need for innovative solutions that leverage technology to enhance efficiency, security, and user satisfaction.

2.2 Inventory Management Systems

IMSs are crucial tools designed to efficiently manage, track, and control inventory levels across various domains. These systems enable organisations to streamline their operations, reduce costs, and enhance customer satisfaction by ensuring the availability of necessary items at the right time and place [15]. An IMS employs methodologies such as the ABC-XYZ analysis to classify inventory items based on value and variability, optimising inventory performance through targeted strategies [15].

Fundamentally, an IMS aims to address key challenges, including maintaining optimal inventory levels, reducing holding costs, and mitigating risks associated with stockouts or overstocking. Techniques like safety stock determination and lot-sizing methods have been widely adopted [16]. Such systems have historically evolved to incorporate technological advancements, enhancing the capability to predict, plan, and execute inventory operations effectively [17].

While conventional IMSs focuses on tangible products, their principles are highly adaptable to managing intangible processes, such as LF item tracking and management. This intersection becomes particularly relevant in environments where the inventory (in this case, lost items) exhibits variability in value, volume, and retrieval demand. IMSs principles, such as classification and optimisation, can be applied to LFSs to streamline processes and enhance user experiences. For instance, using the classification method mentioned before, in a LFS, items could be categorised using an adapted ABC-XYZ framework that enables prioritisation of storage, retrieval, and notification efforts [18], such as the following one:

- Class A-X Items: High-value items with consistent claims. E.g., electronic devices and jewellery.
- Class B-Y Items: Moderate-value items with fluctuating demand. E.g., wallets, bags and clothing.
- Class C-Z Items: Low-value items with irregular claims. E.g., umbrellas and stationery.

The insights from Plinere et al. [19] further support the integration of these methodologies into LFSs. Their case study emphasises the significance of structured inventory management practices for improving operational efficiency. For instance, high-priority items, such as class A-X items, can benefit from focused attention and expedited claim processes, ensuring user satisfaction while reducing storage costs. Furthermore, their findings highlight the value of predictive analytics in addressing slow-moving or stagnant inventory, matching to unclaimed items in LFSs [19]. Technological integration, as illustrated in the case study, offers another avenue for improvement. The use of Radio-Frequency Identification (RFID) and Quick Response (QR) codes in conventional inventory systems ensures accurate tracking and categorisation of items [19], [20]. Applying these technologies in a LF context would improve the accuracy and speed of item retrieval, reducing manual effort and human error. Moreover, the adoption of enterprise resource planning principles, such as imposing a centralised warehouse, would improve transparency and decision-making, possibly enabling a seamless synchronisation of data across departments. Lastly, the Plinere et al. [19] study underlines the importance of standardisation in inventory management policies, e.g., uniform intake procedures, categorisation standards, and clear guidelines for item disposition.

Adapting IMS for LF management would definitely address some unique challenges, improving identification, categorisation, and retrieval processes [15]. Unlike traditional inventory, lost items often have sentimental value or urgent retrieval needs, requiring the system to incorporate real-time tracking and user-friendly interfaces. Moreover, integrating predictive analytics, commonly used in IMS for forecasting demand, would be leveraged to anticipate peak periods of item loss or retrieval, e.g., events or seasons that may influence the volume and types of items lost, allowing proactive resource allocation [16].

2.3 On-Production Solutions

Todo: Write this section.

2.4 Literature Review

2.4.1 Systematic Review

TODO: Write this section.

2.4.2 Object Categorisation

Todo: Write this section.

2.4.3 Information Retrieval

Todo: Write this section.

2.4.4 Object Recommendation

Todo: Write this section.

2.4.5 Privacy and Security

Todo: Write this section.

2.4.6 User Experience

Todo: Write this section.

2.4.7 Gamification

Todo: Write this section.

2.4.8 Challenges and Limitations

Todo: Write this section.

2.5 Designing an IMS

2.5.1 Optimal Approaches

Todo: Write this section.

2.5.2 Best Practices

Todo: Write this section.

2.6 Summary

Todo: Write this section.

CHAPTER 3

Methodolody

"The things we lose have a way of coming back to us in the end,
if not always in the way we expect"
- J.K. Rowling, Harry Potter and the Order of the Phoenix (2003)

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