Designing Human-Robot Collaboration for the Preparation of Personalized Medicines

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ABSTRACT

Advancements in robotics and automation technologies have the potential to enable breakthrough innovations in a variety of industries, and the pharmaceutical sector is no exception. The preparation of galenic formulations, involving the compounding and dispensing of medications, when personalized medicines are needed, e.g., to overcome allergy problems, is a critical process in the field of small scale pharmaceutical manufacturing. Traditionally, this process has relied solely on human expertise of pharmacists and their manual labor, which can be time-consuming, prone to errors, and subject to variations in quality. To overcome these limitations, the use of collaborative robots is envisaged in our project. A collaborative robot can in fact work with the pharmacist synergistically, by improving accuracy and increasing productivity. However, the main challenge is providing the pharmacists with an interactive system that supports them in robot programming. In this paper, we analyze the problem from the users' point of view and propose preliminary low-fidelity prototypes of an interactive system suitable to pharmacists' needs and skills.

CCS CONCEPTS

• **Human-centered computing** → *Collaborative and social computing devices*; • **Computer systems organization** → *External interfaces for robotics.*

KEYWORDS

Human-Machine Interaction, End-User Development, Human-Robot Collaboration, Collaborative Robots

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1 INTRODUCTION

The world's population is growing at an unprecedented rate, and so is the global aging population. According to Eurostat [8], the number of people aged 65 years or over is projected to reach 129,8 million by 2050 in the EU-27, up from 90,5 million in 2019. The median age is projected to increase by 4.5 years between 2019 and 2050, to reach 48.2 years. As people get older, they are more likely to develop diseases and thus need medical and pharmacological treatments. The pharmaceutical sector is constantly growing [11] and more and more types of medicines are being produced. These include galenic formulations prepared by pharmacists. The preparation of galenic formulations, which involves the mixing and blending of various ingredients to create drugs in different forms, such as tablets, capsules, creams, and ointments, is a crucial activity in the drug manufacturing process [14]. Small-scale productions of galenic formulations usually occur at pharmacies, with the aim of personalizing dosages, mixing different active ingredients, overcoming allergy problems, and the like. The current manual process of galenic formulation preparation is highly repetitive and requires a high level of precision and attention to detail [15]. It involves measuring, weighing, and mixing various raw materials according to specific recipes, which can be complex and variable depending on the drug formulation. The process is often performed in a cleanroom environment, which is designed to minimize the risk of contamination and ensure product quality and safety [6]. Furthermore, manual preparation of galenic formulations is a slow and tedious process that requires a lot of time and effort. It is also prone to human errors, such as incorrect measurements, mislabeling, and cross-contamination, which can compromise product quality and safety. Finally, it is a physically demanding task that can cause strain and injury to workers, especially those who perform it for prolonged periods.

To cope with these problems, the use of collaborative robots (cobots) to assist human operators in galenic formulation preparation is being proposed in literature [13]. Collaborative robots are a novel type of industrial robots that can share the space with human workers and collaborate with them to achieve shared goals [17]. The integration of cobots in the preparation of galenic formulations offers several advantages. Firstly, it can increase the speed and efficiency of the process by automating repetitive and time-consuming tasks [13], such as measuring and weighing raw materials. This can free up human operators to focus on more complex and value-added activities, such as recipe formulation and quality control. Secondly,

it can improve product quality and safety by reducing the risk of human errors and cross-contamination [10]. Cobots can also perform tasks that require a high level of precision and consistency, such as mixing and blending, which can lead to more homogeneous and uniform products [2]. Finally, they can enhance the ergonomics and safety of the workplace by reducing the physical strain [5] and exposure to hazardous substances that human operators face during manual preparation of galenic formulations. However, there are still some challenges and limitations to be addressed, such as the cost and complexity of cobot integration in the work practice and the need for specialized training and skills to interact with cobots. For instance, in the case at hand, even though the preparation of galenic formulations is a routine and error-prone activity that can be automated, it keeps on requiring the supervision of a pharmacist both during the definition of the formulation and during preparation execution.

An important issue in the field of collaborative robotics is providing users without any experience of robotics and software programming with techniques that help them define robot tasks, i.e. robot programs [19]. In [3] and [9], we presented an End-User Development (EUD) [1, 12, 16] environment, called CAPIRCI, that provides an intuitive and natural way to program pick-and-place tasks for a collaborative robot. This paper will present the preliminary phases of a project aimed at extending and specializing CAPIRCI to the application domain of the preparation of galenic formulations. Specifically, we will discuss the domain and activity analysis we have carried out with the participation of representatives of end users (pharmacists), and the prototypes developed so far to support pharmacists in the preparation of galenic formulations tailored to their patients through the use of collaborative robots.

2 RESEARCH METHODOLOGY

The methodology to design the EUD environment allowing the programming of collaborative robots that support pharmacists in galenic formulation preparation follows a Human-Centered Artificial Intelligence (AI) approach [18]. The approach is *human-centered* since system design starts from pharmacists' practice, needs and abilities; AI techniques will be exploited to facilitate user-system interaction, by means of natural language interfaces and image processing algorithms. The approach is articulated in three stages that are iteratively executed until a complete and functioning system is obtained:

(1) *Domain analysis and user requirements' definition*: this stage includes the analysis of the domain and of pharmacists' current practice; the definition of users' profile is also part of this stage; different methods have been and will be used to carry out this stage, such as direct observation, structured and unstructured interviews, focus groups, definition of personas and scenarios.
(2) *Prototyping and development*: in this stage the software system supporting the EUD activities of pharmacists aimed to define the domain concepts and tasks of collaborative robots is developed; this stage starts from low-fidelity and high-fidelity prototypes, and develops until system implementation;
(3) *Evaluation*: each prototype or interactive system created along the development cycle is evaluated in terms of usability, user experience and user task load.

At the current stage of the project, we have performed a first domain analysis activity. To limit the scope of the analysis, we decided to focus on the preparation of galenic solutions in granular form, i.e. galenic formulations involving the dissolution of some ingredient during the process and the final production of capsules containing the medicine. We collected information about the current practice of the preparation of this type of galenic formulation. We have then identified the tasks that the collaborative robot may support and started to delineate several mock-ups of the EUD environment to program the collaborative robot. The following sections describes the results achieved so far.

3 DOMAIN ANALYSIS

For the domain analysis we have carried out unstructured interviews with three pharmacists. Beyond describing the process of galenic preparation explaining the most critical steps, pharmacists provided us with technical documentation and videos that we carefully analyzed to acquire some knowledge in the field.

The process of preparing a galenic solution involves several steps to ensure accuracy and efficiency [7]. While the specific process may vary depending on the specific formulation and desired outcome, the general steps involved in the preparation of a galenic solution are illustrated in Figure 1.

During the interviews with pharmacists we explored which of these steps could be improved with the assistance of a collaborative robot. Pharmacists suggested that they are those steps that are repetitive, those that require precision, and those of low added-value. Consequently, we concluded that steps (4) *Mixing and Dissolution* and (8) *Packaging and Storage* are the most suitable to a collaborative robot and we decided to focus our attention on them. More precisely, mixing and dissolution requires a number of repetitive activities, the packaging phase requires a high precision also to avoid material waste, and the storage phase is of low added-value since, at the end of preparation, each capsule must be picked up from the packaging tool and put manually in a container. In the following, these steps are described in more detail.

3.1 Mixing and Dissolution

The mixing and dissolution phase is a crucial step in the preparation of galenic formulations. Achieving uniform mixing and efficient dissolution is essential to ensure consistent drug potency and therapeutic efficacy. The manual mixing and dissolution process can be labor-intensive and time-consuming, particularly when dealing with the production of a large number of capsules or complex formulations. Human operators may encounter challenges in achieving precise mixing ratios, consistent particle size reduction, and optimal dissolution rates. Additionally, manual mixing processes can be prone to human error, leading to batch-to-batch variability and potential quality issues. Robots can perform repetitive tasks with high precision and accuracy, ensuring consistent mixing ratios and particle size reduction. They can precisely control the speed, duration, and force applied during mixing, resulting in more reliable and reproducible results. By eliminating human error, robots can

Figure 1: The steps of galenic solution preparation.

significantly improve batch-to-batch consistency and reduce variations in the dissolution process. This enhances product quality and ensures that the formulated solutions meet the desired specifications. Robots can handle larger volumes and perform mixing and dissolution processes on a larger scale, reducing processing time and increasing overall efficiency. They can work continuously without fatigue, thereby enhancing productivity and throughput. Furthermore, some APIs (Active Pharmaceutical Ingredients) and excipients may pose health risks to human operators, such as exposure to toxic or hazardous substances. By automating the mixing and dissolution process, robots can minimize occupational health and safety concerns, protecting workers from potential harm. Overall, the integration of robots in the mixing and dissolution phase of galenic formulation preparation offers improved precision, consistency, scalability, and safety.

3.2 Packaging and Storage

The packaging phase of galenic solutions involves the proper handling of formulated solutions to maintain their stability, potency, and integrity over time. This phase is crucial to ensure that the medications remain effective and safe for use throughout their shelf life. The packaging phase typically involves transferring the formulated solutions into appropriate containers. It is essential to prevent contamination, degradation, or other undesirable changes that could affect the quality and efficacy of the galenic solutions. Robots can handle the transfer of solutions with precise and consistent movements, minimizing the risk of spillage, cross-contamination, or human errors during the process. They can accurately measure and dispense the appropriate quantities of solutions into containers, ensuring uniformity and reliability. Maintaining proper hygiene and sterility during the packaging phase is crucial to prevent contamination and maintain product integrity; this result can be achieved by equipping them with mechanisms for aseptic handling, reducing the risk of microbial contamination. This solution can also be useful in inventory management by tracking the number of containers, their contents, and their expiration dates. This enables efficient stock rotation, minimizing the risk of using expired solutions and ensuring that an adequate supply of galenic solutions is available when needed. Robots can be programmed to adhere to safety protocols and regulatory requirements, such as handling hazardous substances or complying with Good Manufacturing Practices (GMP). By following standardized procedures consistently, robots contribute to maintaining a safe working environment and ensuring compliance with regulatory guidelines. By employing robots in the packaging phase of galenic solutions, pharmaceutical manufacturers can improve precision, hygiene, traceability, and compliance. The use of automation in this phase helps maintain the quality and efficacy of the formulated solutions, reduces the risk of errors and contamination, and enhances overall operational efficiency.

The storage phase involves transferring the capsules inside a container for delivery to the customer. This task can be performed by the robot through simple pick-and-place and thus avoid a trivial and repetitive task for the pharmacist. By utilizing a cobot for picking capsules and placing them in a container, safety, ergonomic assistance, precision, adaptability, ease of use, scalability, and cost-effectiveness can be improved. These factors contribute to enhanced productivity, product quality, and worker satisfaction.

A key role in the phase of *Packaging and Storage* is played by the *operculator*. The operculator, also known as an operculating machine or sealing machine, is a specialized equipment used in the galenic preparation process to seal capsules after filling. Its main function is to secure the two halves of the capsule together, ensuring proper closure and integrity of the final product. The operculator is equipped with a capsule loading mechanism, which places the bottom halves of the capsules in the correct orientation for filling and sealing. The half capsules are placed in individual cavities within a grid. These cavities correspond to the shape and size of the capsules to be produced. Then the bottom half capsules are filled with the galenic preparation and, once this activity is completed, the operculator ensures proper alignment of the top halves with the bottom halves, by matching the open ends together, ready for sealing. The machine then applies controlled compression force to seal the capsules securely. Finally, the operculator releases the sealed capsules: they are ejected and collected for further processing, inspection, or packaging.

4 SYSTEM PROTOTYPING

CAPIRCI (Chat And Program Industrial Robots through Convenient Interaction) [3, 9] is a EUD environment that allows end users, neither expert in robotics nor in computer programming, to create pick-and-place programs for a collaborative robot. Specifically, CAPIRCI encompasses a hybrid interaction style to enable EUD, which is based on 1) a *chat interface*, where the system and the user use a simple domain-oriented natural language dialogue to define tasks, and 2) a *visual interface,* where the user can drag-and-drop specific types of blocks, representing objects and actions of the domain, but also control statements (e.g., conditionals, repetitions, etc.), to define or modify robot tasks. CAPIRCI also includes a set of libraries of components useful for task definition. The underlying idea is that library components should be defined in CAPIRCI by a domain expert, in order to customize CAPIRCI to the domain at hand. For example, in [9], pick-and-place tasks related to the manipulation of flasks in a laboratory analysis are considered; therefore, the libraries include, among others:

- *Objects*: this library contains the domain objects (e.g., flask, test tube, etc.) that the robot can manipulate; the user can define a new object to be added to this library if it is not yet available.

- *Actions*: this library contains the actions that the robot may execute on the objects, such as rotating or shaking an object; also in this case, the user can define new actions through the CAPIRCI dedicated feature.
- *Locations*: this library contains the domain locations where the robot should place selected objects (e.g., box, tray, etc.); as for objects and actions, the user can define a new location when not available in the library.
- *Controls*: this library contains components to create cycles (e.g., 'Repeat for', 'Loop', 'Do when') and conditionals (e.g., 'When') within a program. Each control block can include other control blocks or action blocks.
- *Tasks*: this library contains previously created robot tasks that can be reused in new programs.

For the sake of the present project, we decided to extend and customize CAPIRCI to support the different types of tasks foreseen in the *Mixing and Dissolution* and *Packaging and Storage* steps discussed above. To this end, the interaction of the pharmacists with the extended version of CAPIRCI will have the following goals:

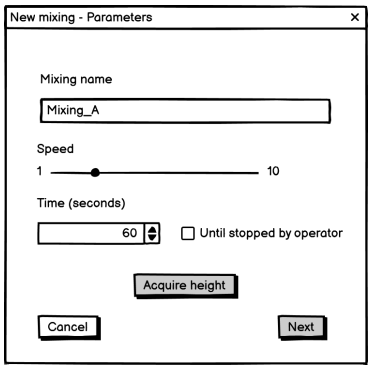
(1) *Domain definition*: the system should support the definition of mixing actions that the robot must be able to carry out in the *Mixing and Dissolution* phase, the definition of operculator grids that the robot must recognize during the *Packaging and Storage* phase, and the definition of containers that the robot must fill to complete the *Packaging and Storage* phase.
(2) *Preparation definition*: the system should support the pharmacist in the definition of preparations of galenic formulations using the library components and interacting with a visual or a chat interface according to their preferences.
(3) *Preparation execution*: the execution of the programmed preparations requires the collaboration between the pharmacists and the robot. The former will do some of the steps identified in the process of galenic solution preparation (see Figure 1) — for example ingredient weighting, and the latter will execute the steps related to mixing, packaging, and storage, always under the control of the human operator.

A reasonable workflow of the pharmacist working alongside the collaborative robot will thus consist of three activities aimed to achieve the goals illustrated above. The following subsections illustrate preliminary solutions to support these activities, which have been designed with the help of low-fidelity prototypes.

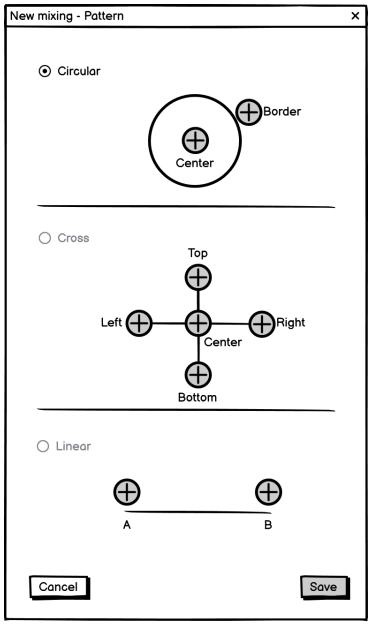
4.1 Domain definition

The core libraries of this new version of CAPIRCI are: *Mixing actions*, *Grids*, *Containers*, and *Preparations*. The library *Preparations* will contain the different preparations of galenic formulations, therefore it will be progressively populated during the preparation definition activity. The other libraries will instead contains all the elements necessary for a preparation definition.

Defining a mixing action. The mixing action will be defined in two steps. In the first one, the following items must be defined: an identifying name, an execution speed, a possible execution time and the height at which it has to be performed (Figure 2a). In the second step it is possible to define the pattern of the mixing action and its associated pivot points, as can be seen in Figure 2b. The points will be acquired through the *teach* action, a common operation when using a collaborative robot. It consists of manually moving the robot arm to the correct position and acquiring the corresponding coordinates by selecting the point in the graphic interface.



(a) Step 1: Definition of the parameters for identification and execution of a mixing action

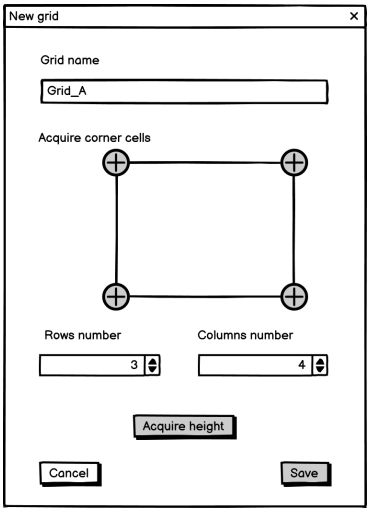


(b) Step 2: Definition of pivotal points to define the pattern of a mixing action

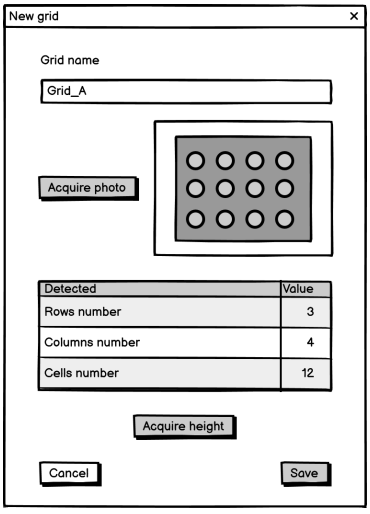
Figure 2: Mixing action definition mockup

Defining a grid. Defining the grid of the operculator is critical for both packaging and storage action as it is necessary to know the location and number of different capsules. A manual or an automatic approach can be adopted to define a grid. The manual approach is based on defining the four corner cells of the grid and the number of rows and columns, then the system can calculate the position of all capsules (Figure 3a). The definition of points will always be done through the *teach* action already introduced for mixing. The automatic approach is based on having everything

recognized through the robot's camera, and then the user will only have to confirm what has been processed (Figure 3b). As can be seen in the mockup, a photo of the grid is captured selecting the button 'Acquire photo'. This will then be processed by image recognition algorithms to highlight the cavities found (the circles in the mockup). The table below will then show the number of rows, columns and cells identified automatically for user confirmation. We will assess which of the two approaches is simpler and more effective through user experiments.



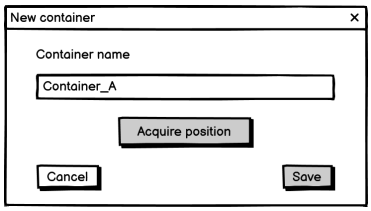
(a) Manual



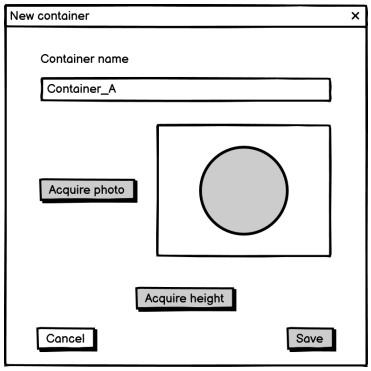
(b) Automatic

Figure 3: Grid definition mockup

Defining a container. The concept of container refers to the final destination of the capsules after the packaging and sealing operation by the user. This can be defined by image recognition, thus taking a picture to identify the container shape and setting the unload height (Figure 4b). The container can also be defined manually by acquiring its position through teach (Figure 4a) for static locations or for destinations that are difficult to identify by image recognition, such as a conveyor belt.



(a) Manual



(b) Automatic

Figure 4: Container definition mockup

4.2 Preparation definition

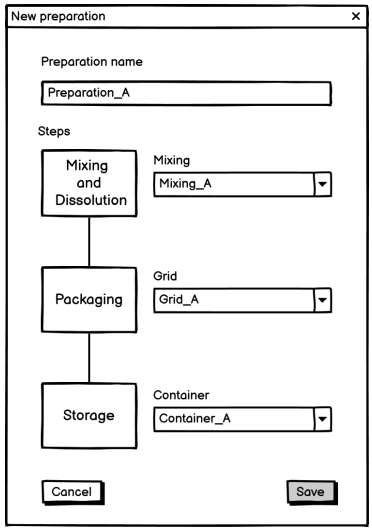
Once all the elements for a preparation have been defined, or reused from a past preparation, they can be assembled to complete the final task (Figure 5a). This step is also feasible with the natural language interface made available through the chat, where the user is requested to tell which are the different elements needed for the preparation (Figure 5b). In [4], we have started to investigate how to integrate the chat of CAPIRCI with OpenAI ChatGPT to make the dialogue more flexible and powerful.

4.3 Preparation execution

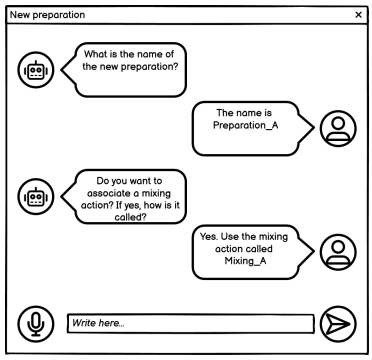
After defining the preparation with the various elements found in the libraries, its execution will become feasible via an appropriate visual interface, facilitating the comprehensive monitoring of each step (Figure 6).

5 CONCLUSION

This work-in-progress paper has presented an ongoing project that focuses on the development of an EUD environment for programming a collaborative robot able to support pharmacists in the preparation of galenic solutions. The project objective is to design a system that not only optimizes the efficiency and accuracy of galenic solution preparation, but also prioritizes the user's needs and preferences. By employing a human-centered design approach, we aim to create an interactive system that is intuitive, easy to use, and enhances the operator's experience. Although the project is still in progress, early stages have shown promising outcomes.



(a) Graphic



(b) Chat

Figure 5: Preparation definition mockup

Further prototyping, iterative testing, and feedback from end users will contribute to refining and enhancing the usability, efficiency, and safety features of the system.

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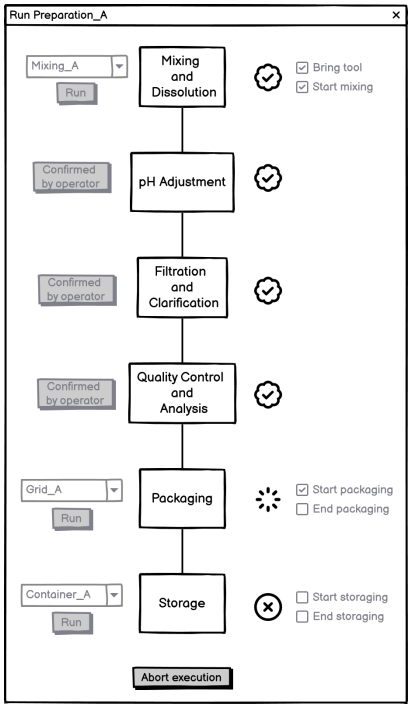

Figure 6: Run preparation mockup

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