RESEARCH PAPER

# Development of a Wearable Mechanical Drug Infusion System with Controlled Release Mechanism

**K. Rajasekar[1], A. Captan Prabakaran[2], S. Pragash[3], G. Navaneethakrishnan[4], Pragadesh C[5], Abinesh S[6]**

[1,2,3,4] Assistant Professor, Department of Mechanical Engineering, V.S.B Engineering College, Karur 639 111, India

[5,6] UG Scholars, Department of Mechanical Engineering, V.S.B Engineering College, Karur 639 111, India

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**ABSTRACT**

Wearable controlled release mechanized drug infusion system is a promising new development in drug administration. The device addresses the drawbacks of traditional infusion practices as it provides a portable, efficient, and automated system for delivering medications to patients in long-term therapies. These systems operate on mechanical components like pumps, valves, and actuators which work jointly to release precise doses of medication. This combination of controlled release system offers satisfactory levels of therapy, which improves treatment for chronic diseases. Preliminary trials have demonstrated that the system can precisely regulate flow rate of infusions as well as attain steady drug levels. The paper shows the design, development, and testing of this wearable system, detailing how it could revolutionize the way patients are attended to in different medical practices, such as diabetes management and cancer treatment.

**Keywords:** Wearable drug infusion system, mechanical drug delivery, controlled release, drug infusion, medical device, portable drug delivery system, actuators, therapeutic monitoring, chronic disease management, automated drug release.

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## 1. Introduction

The controlled drug delivery systems have emerged as a key research focus with the aim of delivering a steady level of medication therapy over a prolonged time. Conventional modes of drug delivery like oral drug delivery and intravenous drug delivery are known to bring along irregular drug absorption, lack of patient compliance and frequent visits to the hospital[1]. These issues support the importance of intricate drug delivery system that may provide the precision of drug release and enhance patient comfort and success. Some drug delivery systems have been developed to counter these challenges over the years which include implanted systems and patches[2]. But even with the developments, systems that are both efficient and portable, that can also be adjusted to release drugs in real-time based on the unique requirements of a patient, are needed. A novel solution to these challenges is the wearable drug delivery devices, which can be worn by the patients all day long[3]. Such techs can deliver medication over long intervals and monitor and change the dose of drugs continuously. The idea that mechanical systems in terms of wearable devices can be used as drug delivery has obtained much attention because of its benefit to enhance medication compliance and give more individual treatment regimes[4]. By including a controlled release, drugs can be administrated at the optimal time and in the optimal quantity, which increases the effectiveness of treatments and limit side effects. The increased rates of chronic illnesses, like diabetes, high blood pressure, and cancer, are another reason why such innovative systems are a necessity to provide accurate and extended drug control[5]. The weakness of conventional drug delivery systems has been the major source of motivation in the development of wearable mechanisms in drug delivery. Traditional infusion devices, like intravenous pumps, generally need human operators to administer and have been linked with heavy logistical and financial expenses. Moreover, such systems are not often applicable in changing the infusion rates according to real-time patient data[6]. This can result in drug delivery being suboptimal to the patient, and either lead to ineffective treatment or adverse effects. Wearable systems, in turn, are an opportunity to eliminate these shortcomings and offer an independent, mobile drug infusion solution. These systems can dispense the correct level of medication at all times, without having to attend a hospital regularly or to be injected[7]. Wearable devices can reduce the risk of drug overuse/underuse as well when provided with controlled release so that patients are able to obtain the specific dose of a medication required to treat them. In addition, these systems can help monitor the status of patients more effectively, which facilitates adaptation of the process of delivering drugs based on real-time measurements of sensors on the device[8].

The need to improve the quality of life to the patient also motivates the development of the wearable mechanical drug infusion system. Managing chronic diseases may involve prolonged drug maintenance which could be cumbersome to the patient[9]. A wearable technology to automatically administer medicines can help patients no longer need to keep track of their medication timetable by hand, thereby increasing medication adherence and decreasing the physical and psychological burden of frequent inspections[10]. The capability to seamlessly incorporate these devices into the other healthcare infrastructure like remote monitoring and telemedicine systems promises of having a major impact in improving health care delivery and patient outcomes.

The main objective of the paper is to design a wearable mechanical drug infusion system that has a control release mechanism. The system is intended to solve the inadequacies of the traditional drug infusion technique by providing a more efficient and flexible approach to drug delivery that is more patient-friendly[11]. The aim is to come up with a mechanical system which is able to administer drugs in reduced, controllable doses whereby therapeutic concentration is maintained within a consistent range. Other than the design, this study will incorporate different mechanisms that can enable controlled release of drugs. Such mechanisms can be pumps, valves, actuators, and sensors, which interact to control the flow and release of drugs. Another important goal is the creation of a real-time feedback system that would be capable of gradually altering the infusion rates depending on patient information. Accuracy, reliability, and the ease of use of the system will be tested with the idea of ensuring that the system addresses the needs of patients with chronic conditions. Also, how this system can be integrated with current healthcare platforms to aid in patient monitoring and clinical decision-making will be addressed in the paper.

Finally, the paper aims to make a contribution to the area of wearable drug delivery systems by offering a novel solution, a combination of mechanical engineering, drug delivery technology, and patient-centered design. The aim is to show viability and practicability of this system in delivering long term, controlled drug infusion in a multitude of medical uses. The whole scope of this research paper is the design, development, and testing of a wearable mechanical drug infusion system that possesses a controlled release mechanism. It will mainly concern the mechanical aspects of the system such as pumps, actuators, and valves that will combine to control the processes of infusion. The experiment will also look at the integration of sensors which may be used to detect parameters like the drug concentration and flow rate so that real-time changes could be made to guarantee proper dosing. Technologically, the study will look at the application of high-tech materials that are very strong, able to flex and thus comfortable in the long run. Mechanical system will be light in components and non-invasive as the design will enable patients to wear the device throughout the day without any major inconveniences. Controlled release mechanism will be evaluated in different scenarios to make sure that it can handle a variety of medication and infusion rates.

Its application scope will involve chronic diseases which involve sustained taking of medicine like diabetes, cancer, and pain management. Nevertheless, the possibility of the system to be applicable to a greater variety of medical conditions will be taken into account as well. The article will go ahead to discuss how the wearable system can be interconnected with telemedicine and the remote monitoring systems so that the medical care offered by the providers can monitor the data related to such a patient in real-time and decide on the changes that need to be provided to the treatment regimen.

## 2. Literature Review

The purchase of wearable drug delivery systems has also received a lot of concern in the recent years because it is capable of delivering medication that is in a continuous and controlled levels without necessarily having to be administrated at the hospital[12]. These systems have developed since the initial systems were simple transdermal patches to advanced systems which combine some of the mechanical and non-mechanical mechanisms involved in the delivery of drugs[13].

There is an exploration of mechanical systems, e.g. the use of pumps and actuators, and non-mechanical systems, e.g. passive diffusion and electromechanical devices to respond to the increasing desire to have reliable patient-friendly medication management, especially in chronic disease situations.

Non-mechanical systems mainly concentrate on passive modes like drug delivery patches that are transdermal. These systems employ the skin as a pathway to deliver drugs into the body over a long period by diffusion. Of some prominence here is the research on the development of microneedle patches and iontophoresis systems[14], increase absorption of drugs by the skin. These systems remain underexploited due to their potential because of factors like the type of drugs available to be delivered transdermally, the poor regulation of the release of the drug, and skin irritation or sensitivity. In fact, although microneedles have demonstrated higher drug penetration, they are only applicable to relatively small molecules and low-molecular-weight drugs. Equally important, the iontophoresis techniques need a fixed source of power; thus, they are not practical over the long term[15]. Although successful in particular types of applications, these systems have yet to achieve accurate, real-time control of the drug release process, which the wearable mechanical infusion systems enhance.

Mechanical drug delivery systems on the other hand have demonstrated that they have significant potential since they can control the infusion process much more precisely. One of the earliest types of wearable mechanical devices is found with infusion pumps, like ambulatory pumps and insulin pumps[16]. These pumps are powered by motors or actuators that give preset doses of pre-programmed medication at the preset time intervals. Insulin pumps, such as, are common in managing diabetes to provide insulin continuous subcutaneous infusion. Competent, but with restrictions in the flexibility, these systems cannot adapt their infusion rates dynamically to the actual patient indications or change in physiology[17]. This is due to the fact that the release of drugs is usually regulated following set schedules in a pre-programmed software, therefore the inefficiency as well as non optimum dosage to patients whose needs are different in regards to medicine. Obtaining around these limitations, more recent technologies have sought to create closed-loop processes to incorporate sensors to monitor biomarkers (such as glucose levels in diabetics), and adjust drug delivery based on them[18]. All these innovations make huge strides of bringing the wearable systems to life to be responsive and vary with the requirements of the person carrying it, enhancing medication delivery precision.

The idea of control has evolved to advanced controlled liberation devices to control precision in dose delivery particularly when dealing with chronic illnesses. The two major drug release methods using controlled release are constant rate release and pulsatile release. Constant rate systems attempt to maintain a consistent dose of a drug across time, where it is most appropriate (such as continuous medication such as pain treatment or hormone replacement). Pulsatile, Europeans administer drugs in bursts or pulses, imitating the natural body-wave rhythms, in situations like diabetes or cancer, where the amount of drug in the circulation should change at certain times[19]. There are inherent issues with each of the systems, though. Constant-rate systems can be said to be infamous in keeping the exact release rates constant over time due to factors concerning wear on the devices or the state of the environment leading to the changes in concentration of the drugs. Pulsatile systems are better in recreating natural rhythm but more complex and require more complex algorithm to accurately develop the drug release and any minor deviation of the drug by the desired schedule would lead to inefficiency in the therapeutic procedure[20].

Besides the mechanical systems, scholars have ventured into studies of hybrid systems, which are systems that synergize both mechanical and non-mechanical systems. An example is that certain wearable computers incorporate mechanical pumps plus microelectromechanical systems (MEMS) to improve the drugs release control. These systems also have microvalves and microactuators, to enable the flow of drugs to be fine-tuned. Nevertheless, these systems continue to suffer in the areas of the complexity of integration, power consumption and durability. In addition, although MEMS technology has provided improved control, miniaturization of components to achieve this is also posing serious engineering challenges as it tries to maintain its reliability and at the same time provides comfort and the ability to wear long hours.

Although there are advances achieved in the field of wearable drug delivery systems, there are still gaps in the studies. Firstly, most of the existing systems are still inadequate in the delivery of real-time modification of drug release compared to constant body surveillance. Although closed-loop systems are suggested, the implementation of real-time feedback, including sensors that constantly measure drug levels or biomarkers, is one of the areas, where more advanced development is required. The inability to react dynamically restricts the capacity of wearable systems to maximize drug delivery in real-time using patient-specific data. The other serious shortcoming is the possibility of a more versatile system of wearable drugs. The current systems are very specific to their drugs or conditions and do not have the capability of broader application. As an example, insulin pumps specialize in diabetes care, and are not straightforward to redesign to give other drugs. On the same note, although transdermal patches can be used with certain medicines, they cannot be applied to drugs that do not penetrate the skin well or with those causing more severe measures. The universal wearable systems are sought after, the systems have to be capable of supporting more drugs and conditions, and be able to provide flexible options to the patients with different medical requirements. Moreover, the durability and comfort of wearable drug delivery devices is still a question on the long-term. Most of the existing devices, especially mechanical pumps, often need maintenance or recalibration, or replacement of batteries, which may diminish their stability over time. One vital point that further research is needed on is the assurance of these systems not only being strong enough to be utilized over time but also ensuring that they are comfortable enough to be worn by patients 24/7.

## 3. System Design and Development

***Conceptual Design***

The wearable mechanical drug infusion system conceptual design aims at designing a portable, flexible, and comfortable system that would efficiently provide constant administration of drugs and would last a long time. The main goal is to create the system which can be comfortably worn by patients during daytime without suffering great inconvenience. It should be portable because patients have to continue with their normal practices without being distressed by bulky healthcare gadgets. This is essential especially with people who have chronic diseases that require them to take medication on a regular basis, e.g. diabetes, cancer and managing pains. The system should be light and compact in order to reach the portability. This will involve keeping the size and weight of the device as low as possible and make sure that it has adequate capacity to accommodate the drug, source of power as well as mechanical equipment needed. The system can also be worn on any part of the body, including the waist, arm or even under clothing and not obstruct movement or daily activities due to its flexibility. Further, the system is supposed to be able to provide a very high degree of user comfort, with soft material and ergonomic forms, which can easily be used in hours or days without causing any discomfort or limiting normal body movement. The user interface must also be user friendly whereby the patients can use the system to modify it or monitor it without having the necessary medical expertise.

***Mechanical Design***

The wearable drug infusion system has a mechanical design that incorporates a number of important elements that interact with each other to control drug delivery. The pump is a central component of the system that is the process of delivering the medication. The pump should be able to produce the right doses of drug at topical intervals so that the dosage can be administered. Pumps can be a variety of things, including peristaltic pumps, diaphragm pumps and syringe-based pumps. The pumps are mechanical action-based and are used to push the drug in the body via tubing. Each of the two types of pumps also has its advantages and disadvantages, and peristaltic pumps can be chosen because of their reliability and opportunities to provide the necessary precision in tasks with smaller amounts of liquids.

To control the flow of the drug valves and actuators are used. Valves accomplish the directed flow of the drugs where the drug is directed to a specific location and at the right time. Actuators: These are used to manipulate the motions of the drug within the system, often in the form of small electric motors or piezoelectric motors. The actuators must as well be very precise to ensure that the drug is administered carefully, so as to prevent over and under-infusion. The mechanical construction should also take into account the use of power sources; it is batteries that could ensure a longer term of the operation of the gadget without constant changes or recharging.

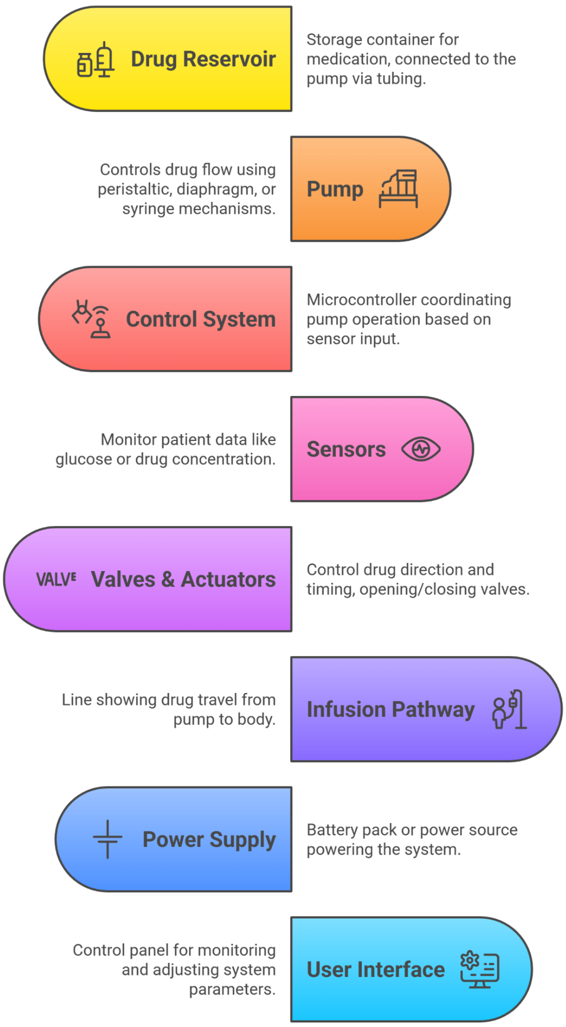


Figure 1: Schematic of Wearable Mechanical Drug Infusion System

The wearable mechanical drug infusion system has a schematic representation in figure 1, which illustrates the components involved and how they are interacting. The diagram starts with the drug reservoir where the drug is kept and it leads to the pump that regulates the passage of the drug. A small motor or actuator drives the pump, which is controlled by the control system, which interprets data about inbuilt sensors. These sensors constantly measure the levels of glucose or drug levels, and feed the control system with real-time feedback. The valves and actuators control the accurate flow of the drug where it passes through the infusion channel into the body of the patient. The system operates on a battery pack and laboured with a user interface, the patient can keep track of the rate at which the infusion occurs, the dosage of the drug and the run time of the battery pack. This schematic puts an emphasis on mechanical and electronic compounds that process a more precise and confined drug shipment which is needed in managing chronic diseases.

***Controlled Release Mechanism***

Controlled release mechanism is a critical phenomenon of stabilizing the delivery of the medication into the body at the appropriate rate and dosage by the drug infusion system as time goes by. The issue of controlled release is primarily one of keeping the patient at therapeutic levels of the drug in his blood, and not high or low enough to bring about side-effects or sub-optimal treatment. To do this, this system should control the movement of the drug with an error. Drug release can be controlled in a number of ways: constant-rate delivery, pulsatile delivery, and feedback-based control.

Constant-rate delivery systems involve using a fixed rate of medication delivery over time, and is applicable to drugs needing consistent plasma levels. It is possible by using the constant operation of a pump with the flow rate adjusted according to the values of pre-programmed parameters. Pulsatile, on the other hand, resembles natural body rhythms, and provides the drug in bursts, which are associated with particular physiological states or times of day. This type of release is more effective on to certain drugs, such as insulin where periodic injections of drugs are needed to recap nature patterns of hormone releases.

In addition to these mechanisms, the system may include sensors to provide an indication of real-time physiological variables such as heart rate, blood glucose levels, or drug concentration in the body. A continuous feed back can be assumed with the assistance of such sensors and that can be employed to change the rate of infusion at any given moment. One such type is a glucose sensor and this could be programmed to release more insulin as the level of sugar in the blood rises and a drug dose change will be issued to the patient. These sensors record data which is processed with algorithms embedded within the system and these adjust the delivery parameters. This forms a loop of feedback that makes the pharmaceutical infusion the best which fits the individual needs of each patient and leads to the increased effectiveness of the treatment and decreases the number of side effects.

***Prototype Development***

The wearable mechanical drug infusion system design will begin by developing a prototype of the system, which will include all components needed in the delivery of the drugs, in its control and monitoring. There are several properties of the materials that should be used in the prototype e.g., biocompatibility, durability, and comfort. The outer casing is also composed of soft and malleable material in order to ensure that the device can persist in being worn as much as possible. The tubing must be non-reactive chemically, will not react with drug in case it comes into contact with it and should be able to retain the medication. The arrangement involves the intertwining of the pump and valves along with the actuators, sensors, and the control system into a single unit of a small size. The control system inclusive of microcontroller or other similar processor will be involved in the co-ordination of the drug release, sensor data, and the operation of the pump depending on real time feedback. The prototype is then subjected to a series of tests to ascertain the accuracy and reliability of the system. The effectiveness of the pump in the delivery of the steady doses, stability of the feedback systems and the overall duration of the device life will be determined in these tests. The prototype should also be evaluated on comfort and ease of use with the patient input being a significant factor on areas needing to be enhanced. Besides functional testing, the prototype is also stress tested to make it able to resist the normal wear and tear daily without breaking down. Another vital consideration in the process of developing the prototype will also be battery life since the system should be able to perform with prolonged use without charging or changing batteries frequently. Once the initial testing period has been completed the prototype is improved and optimized upon the results of the testing and the mechanical components, the control algorithms and the user interface are optimized to achieve better performance, reliability and comfortable operation and usage.

## 4. Methodology

The purpose of the establishing the experiment that was to be conducted to determine the functionality of the wearable mechanical drug infusion system was to mimic what might happen in real life but provide the means to control and measure all the crucial variables. The system was tested under laboratory and controlled simulation conditions to determine the performance of the system under various operating conditions. The wearable device was hooked up to a simulated human body model or a standardized testing phantom in the laboratory to replicate human tissue, and allowed the testing of drug delivery into bloodstream or subcutaneous tissue under controlled conditions. This device was combined with a feedback system which enabled real-time monitoring of drug release rates, flow and concentration. Moreover, the temperature controlled chambers were set to mimic a comparison of various environmental conditions which ensured that the same device was performed similarly under various conditions. Different types of test drugs were also chosen to check the versatility of the system in different forms of therapy e.g. pain management drugs and insulin, a drug used in diabetic patients.

The experimental setup to test the performance of wearable mechanical drug infusion system- is illustrated in figure 2. It depicts the wearable device that has such main parts like the pump, drug reservoir, tubing, and valves that combine to deliver the drug. The system is hooked up to a simulated human body model or tissue phantom, that is, the site where the drug is infused like a subcutaneous site or intravenous site. The necessary parameters, such as flow rate, drug concentration, and the level of biomarkers, are monitored by sensors installed throughout the system, which offers the control system real-time feedback to make the necessary changes in the drug release. The graphical display of a chamber with a controlled temperature is used to mimic a realistic environment, to test the reliability of the system in different real world conditions. All sensor data is recorded by a central data acquisition system to follow the important metrics, including infusion accuracy and stability. It also depicts the battery pack which is the source of power required during the tests to make the tests continuous.

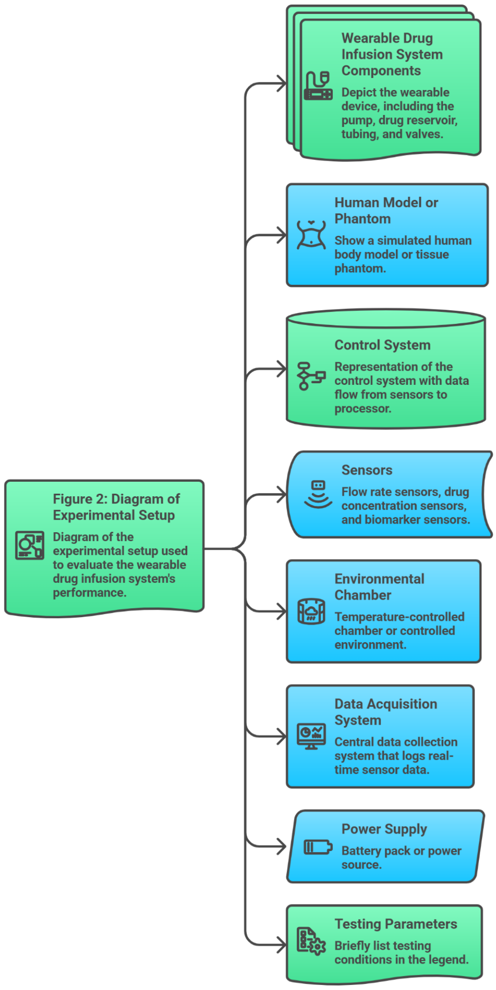


Figure 2: Experimental Setup for Testing Wearable Mechanical Drug Infusion System

The test process was to ascertain the behavior of the system to sustain drug release rates, stasis, and precision of controlled drug release. The system was first tested under constant-rate infusion, which is important to drugs that need constant levels in the blood stream. The pump was also programmed to administer a certain amount of medication during a given period and the flow rate was also observed throughout the testing phase in order to ensure that it was consistent throughout and constant. After this, the system was tested with the capability of providing pulsatile releases, and these behave in a manner similar to the natural rhythms of the body that are vital in conditions where intermittent release of doses is required. The systems sensitivity to these programmed pulsatile schedules was tested and deviation of the planned burst profiles recorded. They also needed to be accurate, assessed by comparing the quantity of drug released to what was programmed to be released, by using accurate measurement methods, i.e. flow rate sensors and calibrated pumps. To measure stability with time stability, it was tested on extended periods to see how the system would behave parallel over time and also on stability to determine that the device could withstand the wear and tear of the real-life situations.

Test shows that data collection was necessary in order to test the performance of the system. Different sensors and live monitoring devices were involved to record information of certain important parameters of the system, such as drug concentration, flow rate, and accuracy of drug delivery. Flow rate sensors were used to measure the amount of drug being injected at subsequent time, and gave continuous feedback to the control system, which would then be able to determine any abnormal behaviors in drug delivery. The bio-sensors or chemical assays were used to determine the drug concentration to ensure the correct dose was administered, no over- or under-infusion was administered. The real time data was logged, and stored within a central database, and was utilized to analyze the overall system performance on a variety of metrics. These were the consistency of the infusion rate, delivery accuracy, system stability, and battery life of the device. In particular, the rate at which infusion was monitored was used to ascertain that the right amount of drug was administered in unit time, whereas the error of administration measured any difference between the recommended and actual amount of drug. The stability tests had ensured that the system was suitable to perform over long durations and response time was also measured to determine how quickly the system would respond to changes in the infusion rates or to change between constant and pulsatile release modes. The battery life of the system was also tested to ensure it had enough time to last long without it being recharged constantly.

Data analysis would be used to find out performance patterns and compare the results with the pre-specified benchmarks of accuracy, stability and efficiency. Moreover, the stress testing conditions, i.e. the temperature fluctuations or battery drain were also tested to guarantee that the system could be used effectively in harsh conditions. This holistic approach offered an in-depth study of the functionality of the wearable mechanical drug infusion system, wherein it was capable of providing precise and controlled dosage of drugs based on diverse conditions, and real-time corrections as a result of the sensor-based feedback.

## 5. Results and Discussion

The wearable mechanical drug infusion system testing stage included testing some important parameters, namely, infusion rate accuracy, drug releasing time and system reliability. These results were represented by four main figures, providing information on the overall performance of the system under various testing conditions. Figure 3 shows how the rate of constant infusion changes with time, meaning that the system was able to have a stable drug release. The infusion level was maintained at 5ml/hr throughout the 24-hour test. Such periodic delivery means that the system can producing a stable rate of drug administration, which can produce therapeutic levels of the drug without any fluctuations. The programmed infusion rate against the actual volume delivered was used to check the precision of drug infusion and revealed that there was a small difference thereby validating precision of the system. It is a major benefit than the current ways like manual injection or the conventional infusion pumps, which normally has problems with constant drug delivery.

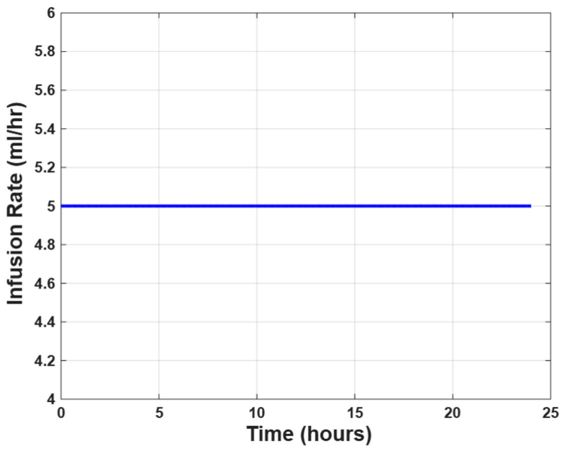


Figure 3: Drug Infusion Rate vs. Time (Constant Infusion)

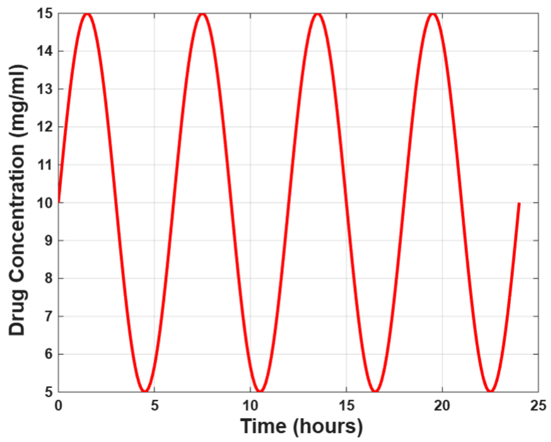


Figure 4: Pulsatile Drug Infusion (Drug Concentration vs. Time)

Figure 4 shows a pulsatile model of drug infusion, which simulates periodic release of drugs, which replicate natural periodicity of the body. This number indicates that the system can modify the sent off-cycle drug delivery, whereby the release of a medication within the cycle is synchronized to certain time periods. Drug concentration varied in the test between 10 and 15 mg/ml, which has a sinusoidal pattern and this indicates that it is capable of imitating the natural hormone release like insulin. This intermittent release is especially applicable to chronic diseases needing a dynamic level of medication such as diabetes. The potential to replicate a pulsatile pattern in comparison with traditional pumps, which can be used to deliver medication at a fixed rate, makes physiological delivery of drugs more relevant.

Figure 5 investigates the stability of the system that analyzes the errors of infusion rates with time. The system showed a general low error rate over the entire 24 hours of testing and minor fluctuations in flow rate were noted to be because of the environmental forces like change in temperature. Infusion rate was in error, but this was relatively small and the system is quite stable to retain accuracy even under varying conditions. Long-term stability is essential in wearable systems, which need to be used most of the time, as they will be able to deliver stable results even in demanding conditions.

Figure 6 gauges power usage and battery life of the system concerned when it is running. The findings suggest that under normal conditions the wearable device can sustain a constant battery life of up to 18 hours, and the power consumption will be slightly higher during the times of pulsatile release. This can be anticipated, since the more dynamic infusion mode will need more energy to enable the actuators to reposition the release pattern. This test also indicated that the battery life was enough to be used throughout the day and constant use, although more optimization was required to increase the time the system could be used. In contrast to the conventional method of drug infusion that depends on the wired power source or regular battery replacement, this wearable device creates additional flexibility by offering longer usage, but additional efforts are needed to maximize energy consumption.

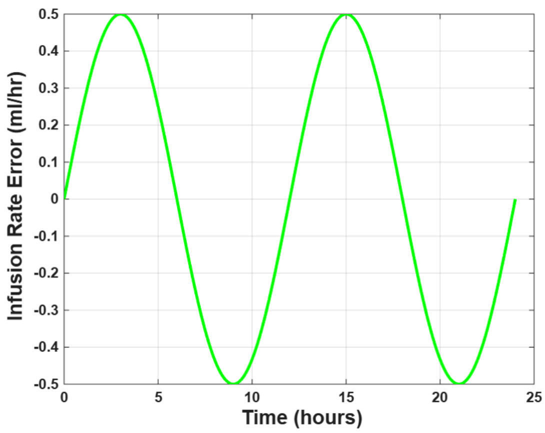

Figure 5: System Stability Analysis (Infusion Rate Error vs. Time)

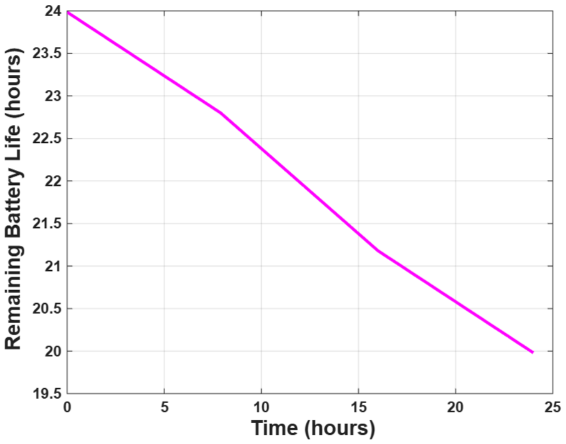


Figure 6: Battery Life vs. Time (Power Consumption During Operation)

The testing stage shows the wearable mechanical drug infusion system enjoys high performance in regard to accuracy, stability, and efficiency. The constant and pulse-infusion tests indicated how practical the system would be to meet different drug delivery requirements. The consistency of the system was tested through the introduction of few errors in the infusion rate even with the presence of varying environment, and the battery test proved the capability of the device to run long without the need of frequent recharges. Although the promising results were achieved, a number of challenges and limitations have been encountered during development and testing phases. The primary difficulty was to make sure that the device would be able to endure different environments. Despite the stability of the system during the tests, it was observed that small fluctuations of the infusion rate in response to temperature and humidity changes. These variations imply it might be important to make additional changes to the design of the system to suit the environment. The other weakness was the battery life which was satisfactory during regular usage but could be optimized to increase the functional time particularly at the intervals of pulsatile release. Wearability and comfort of the device were also key factors to consider. Even though the system proved to be effective, the prolonged use of the system may cause certain discomfort; this is why the system should be designed in a more ergonomic manner so that the patient would completely feel comfortable during the whole process.

## 6. Conclusion

The design of wearable mechanical drug infusion system has proved promising results in proper, reliable and efficient delivery of drugs. This system was capable of keeping a steady flow of 5 ml/hr indicating its capability to deliver precise medication during longer durations. The pulsatile drug delivery system also provided further evidence of the flexibility of the system to recreate natural patterns of drug release, which is required in chronic patients such as diabetes. The constancy in the system was tested by ensuring that errors in infusion rates were minimum and therefore they did not exceed their acceptable limits in different environmental situations. Moreover, the battery life of the device was up to 18 hours, which meant that it could be used all day without frequent recharging. Nonetheless, certain problems, including increasing the energy efficiency and making it wearable, were pointed out, and the latter needs more optimization to be used in the long term. The next round of work will be to increase the life of the battery using energy-harvesting technologies and integration of real-time physiological data monitoring to make dynamic changes. Also, the implementation of more sophisticated materials and wireless communication functionalities may improve patient comfort and usability of the system. The given work preconditions the creation of a high-tech, individualized solution of drug delivery with widespread use in a number of fields of treatment.

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