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The House of Carbs: Personalized Carbohydrate Dispenser for People with Diabetes

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Abstract. Patients with diabetes are often worried about having low blood glucose because of the unpleasant feeling and possible dangerous situations this can lead to. This can make patients consume more carbohydrates than necessary. Ad-hoc carbohydrate estimation and dosing by the patients can be unreliable and may produce unwanted periods of high blood glucose. In this paper we present a system that automatically estimates and dispenses the amount of juice (or similar) according to the current patients' blood glucose values. The system is remotely accessible and customizable from a chatbot, exploits sensors and actuators to dispense the necessary amount of liquid carbohydrates. It relies on a cloud solution (Nightscout) to acquire the patient's blood glucose values, which are constantly updated thanks to a commercial wearable continuous glucose monitor (CGM).

Keywords. Diabetes, Hypoglycemia, Carbohydrates, Cyber-Physical Systems, Internet of Things

1. Introduction

Measuring and managing blood glucose concentration is a key element in diabetes care, especially in type 1 diabetes. Since the first real time continuous glucose monitor (CGM) was provided for patients in 2001 [1], its relevance in both ambulatory diabetes care and clinical research has increased over the years [2]. Decreasing size, weight, complexity and cost of CGM sensors/devices have increased usage and dissemination [3]. CGMs have helped patients to improve their quality of life, by increasing their confidence in self-management of their disease.

In diseases such as diabetes, due to the availability of low cost technologies, well-educated patients, or engaged relatives, it has become possible to formulate, develop and distribute solutions that aim to answer specific needs in managing the disease, based on the patients individual situation [4].

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In this study we show how it is possible to integrate patient-initiated solutions such as Nightscout [5], different sensors, mobile technologies and actuators, as concrete tools in patients' daily life. The system referred to as "The House of Carbs", was developed in collaboration with patients, to help them in one of the daily challenges in insulin-treated diabetes, namely low blood glucose episodes (hypoglycemia). The goal was to design a solution that can automatically dose an estimated amount of juice (or similar) from a reservoir to a glass, when required. The motivation is to avoid serious hypoglycemia situations and in preventing subsequent high levels of blood glucose (hyperglycemia) due to intake of more carbohydrates than necessary. We aim in stabilizing the blood glucose and avoid the "Roller coaster effect", when the blood glucose is fluctuating between levels outside the normal range.

This paper is organized as follows: first we describe the methods used, and then we present the designed prototype and data from 2 months of use by two patients. The paper concludes with limitations and challenges for integrating sensors and actuators in a cyber-physical system for people with type 1 diabetes.

2. Methods

A literature review was conducted for mapping the available systems for managing hypoglycemia. The outcomes of this review and a patient-involvement approach were then used to define the system functionalities and requirements. Patients' needs and expectations were also used to improve the software during the prototype testing phase.

Figure 1 shows the conceptual overview of the system, and how it interacts with external hardware and software components.

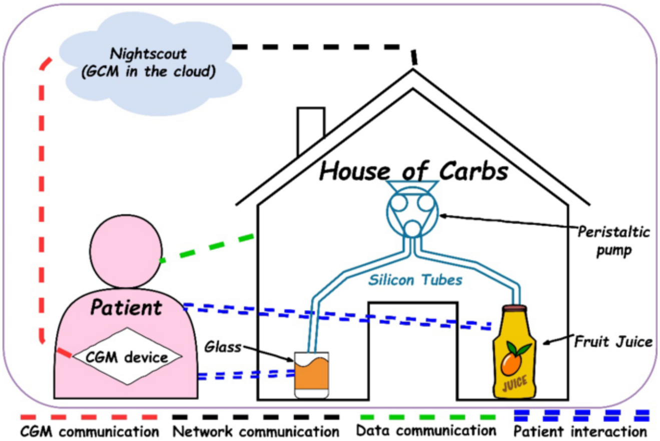

Figure 1: House of Carbs – a conceptual overview

Nightscout provides the real time data necessary to detect the hypoglycemic episodes and to evaluate the result achieved by the liquid carbohydrates delivery.

The patient must be an active part of the system, (s)he will have to insert the silicon tube inside the juice container and glass. Furthermore, the patient needs to provide the information about the juice's content of carbohydrates and the web address of the Nightscout platform. In addition, (s)he is responsible for proper maintenance and use of the system, e.g. if the glass is removed from the system, the consequent assumption is that the patient has drunk its content, and it needs to be replaced with a new glass before the next delivery.

3. Results

3.1. The prototype "House of carbs"

We built a fully functioning prototype using a Raspberry Pi 3 and an add-on board to control two high-power DC motors. The "House of carbs" includes an additional chatbot application to remotely control the hardware (e.g., clear the pump, remotely turn off the machine), define system parameters (e.g., carbohydrate content and amount of juice present, Nightscout address, units), and send notifications (e.g., "dose ready to be picked up", "glass removed"), see Figure 2.

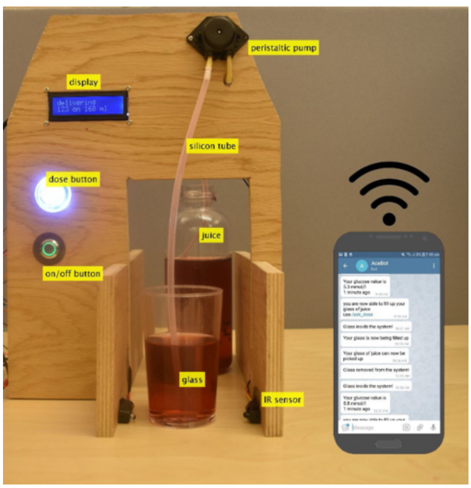

Figure 2: The prototype "House of Carbs", based on communication with Dexcom G4 CGM and the Nightscout platform.

The system reports its status and the blood glucose values through a LCD display. The detection of the glass represents a critical issue in this system, and this is done by IR sensor. In case the glass is not detected, the system will block any juice distribution and users will receive a notification about the missing glass via the chatbot.

3.2. Treatment of hypoglycemia and prevention

A common approach to treat hypoglycemia is the 15/15 rule [6] (eat 15 grams of carbohydrate and wait 15 minutes), especially effective when using liquid carbohydrate sources [7]. This rule suggests checking the blood glucose value after 15 minutes and repeating the procedure if the glucose value is still under 3.9 mmol/L (70 mg/dL). The proposed system was designed together with real users, revealing the importance of automatically detect hypoglycemic episodes and deliver carbohydrates. The amount of carbohydrates was made personalizable, and the users can choose the amount of delivered carbohydrates (e.g. 20g instead of 15g). According to their suggestion, the system allows patient to request carbohydrates when expecting hypoglycemia, especially relevant before an intense activity (e.g., physical activity) [8] or for safety reason before activities that may be risky (e.g. driving a car) [1].

3.3. Testing

The trial ran for two months involving two persons with type 1 diabetes. During this period the system logged 3116 different CGM readings and distributed 52 doses of carbohydrates. The system delivered either 15 or 20 grams of carbohydrates each time, based on the patient's preferences. Table 1 presents the summary of these distributions.

Table 1: Successful juice distribution divided by patient and dose type (hypoglycemic or request)

Patient no	Carbs (g)	Total doses	Description	Value
1	15	9	Average hypoglycemic glucose value detected before the dose (mean ± SD)	3.48 ± 0.51 mmol/L
			Average glucose value after approx. 15 minutes (mean ± SD)	4.17 ± 0.79 mmol/L
	20	20	Average hypoglycemic glucose value detected before the dose (mean ± SD)	3.56 ± 0.43 mmol/L
			Average glucose value after approx. 15 minutes (mean ± SD)	4.13 ± 1.08 mmol/L
2	20	2	Average hypoglycemic glucose value detected before the dose (mean ± SD)	3.9 ± 0 mmol/L
			Average glucose value detected after the dose (mean ± SD)	4.7 ± 0 mmol/L
1	15	6	Average glucose value detected before dose request (mean ± SD)	4.75± 0.59 mmol/L
			Average glucose value after approx. 20 minutes (mean ± SD)	4.17 ± 1.38 mmol/L
	20	15	Average glucose value detected before dose request (mean ± SD)	4.85 ± 0.62 mmol/L
			Average glucose value after approx. 19 minutes (mean ± SD)	4.77 ± 0.83 mmol/L

4. Discussion

Health systems involving sensors and actuators need to be robust and adaptable to unexpected conditions and subsystem failures [9]. However, no component is perfectly reliable, and the physical environment will produce unexpected conditions.

The presented system integrates the open source diabetes-monitoring tool Nightscout, that has an informational and educational purposes only. Thus, the CGM data from Nightscout were the unique source of information in this system – which only was made to present future possibilities. All the designed functionalities are dependent of this data, and when no data are received from Nightscout, the system is not able to provide these functionalities. Additionally, to maximize the accuracy of the system, the sensors connected to Nighscout must be calibrated according to the device producer's instructions. It is important to make it clear that the test period was short, the number of subjects were limited, and the patient participants have more than 20 years of diabetes experience and involved in different diabetes research projects.

4.1. Practical limitations

Designing such a system requires several assumptions. For example, that the source of carbohydrates is a safe and efficient liquid, the target glass has a capacity that can hold the maximum delivered dose, and both the source and target containers need to be clean due to hygienic reasons. Also, the entered settings need to be accurate for the system to deliver the right doses. If the user enters incorrect information (e.g., the carbohydrates content of the juice), the system may not help the user to achieve a healthy blood glucose level. Furthermore, the chatbot component of the system can potentially be accessed by anyone and therefore additional security solutions is needed to avoid abuse or misuse.

5. Conclusion

The main contribution of this research is demonstrating the design of a practical system able to monitor and prevent hypo- and hyperglycemia. The system has been designed using a patient driven approach, and integrates some already existing components.

The absorption of glucose into the bloodstream was shown to be effective for the two test-persons, after one or more delivered doses, in average after 15-20 minutes. They were satisfied with the use of the system and even surprised how it was able to stabilize the blood glucose. No hyperglycemia episodes or "Roller coaster effect" were caused by the system.

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