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ORIGINAL RESEARCH

Human robot interaction as a service for combatting COVID-19: an experimental case study

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Abstract
COVID-19 pandemic has changed today's routines in a variety of fields such as society, economics, health, etc. It is surely known that the most powerful weapon to fight against the disease is the social distancing. Hence, it is strongly recommended by the authorities to decrease human to human interaction (HHI) in order to stop the spread. However, daily routine of people must continue somehow, because of the fact that it is not known when the pandemic will end permanently. Thus, new approaches should be adapted in social environments for COVID-19 prevention. Human robot interaction (HRI) can be seen as a vital mechanism to provide risk free routines in the society. For this purpose, we offer a human robot interaction as a service (HRIaaS) for eatery locations such as restaurants, cafes, etc. where customers should interact with the staff. The proposed service aims to utilize personal smartphones and decrease the number of HHIs for such environments in which strange people involved. Moreover, an experimental case study is conducted to obtain an evaluation with a real world scenario when the proposed service is used versus a contemporary routine with HHIs. The evaluation results show that an average reduction of 41% is achieved per customer in the number of HHIs between customers and serving staff.

Keywords Human robot interaction · Cloud services · Combatting COVID-19 · Post pandemic

1 Introduction

SARS-CoV-2 virus and its variants have begun to spread over the world since late 2019. Initial studies have shown that the spread of the virus is extreme. Li et al. (2020) reports the ratio of documented and undocumented cases in China, where the first confirmed cases have arisen. They also claim that there is a considerable amount of undocumented cases that leads the spread over Europe. Similarly, Liu et al. (2020) reports an exponential grow at the spread rate, according to the initial findings. Moreover, some environmental components such as wind and temperature also have an increasing effect on the spread as examined in the study of Coşkun et al. (2020). All the given claims have caused a rapid dissemination of the virus throughout the world. Hence, the World Health Organization (WHO) announced the situation as the COVID-19 pandemic soon after.

There is an immense effort on (1) seeking treatment and (2) prevention strategies for the disease since the COVID-19 pandemic declaration. On one hand, medicines are the major treatment tools to get over the disease. However, there is a small number of attempts succeeded to treat the new variant of the SARS-CoV-2 virus such as the medicine produced by Pfizer. Moreover, other studies also continue, but it takes too many times to come up with a successful treatment because of the phases included in medicine production. On the other hand, prevention can be achieved by vaccines and social distancing to decline the spread of the virus. Several vaccine studies have arisen, since early pandemic. It is shown that some of them are able to protect an individual from the virus with a remarkable success ratio as stated by Forni and Mantovani (2021). However, considering the vaccines have been developed so far, there is not an exact cure for the spread of the virus yet. Peiris and Leung (2020) reveals the concerns about the effectiveness of vaccines for virus dissemination. Similarly, Christie et al. (2021) asserts that people get vaccinated are still prone to transport the virus, according to the evidence collected from countries in which a vaccination campaign is carried out. Moreover, mutation of the virus brings about new variants according to Kaur

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and Gupta (2020) and this situation threatens the success of vaccines. Thus, considering the deficits and vulnerabilities for medicine production and vaccine development, social distancing can be seen as the most valuable weapon for a potent prevention that people can use against the virus as stated in Qian and Jiang (2020) as well as highlighted in Kaur and Gupta (2020).

Social distancing is completely safe, but is not achievable most of the times in daily life routine. It requires regulation not only by individuals, but also the authorities. As a consequence, it can be asserted that daily routines have been affected severely because of individual social distancing and government imposition such as a lockdown. Moreover, the end of the pandemic cannot be foreseen clearly. Thus, we have to adapt our daily routines according to the pandemic conditions for a prominent prevention from the virus. Human-robot interaction (HRI) can be offered as a solution to provide safe environments with less human-human interactions (HHI) avoiding individual contacts. Gittens (2021) carries out a study to show how efficient of using HRI to provide physically distanced environments in daily routine during the COVID-19 pandemic. The authors claim that the remote HRI mechanism offered in their study is adopted by the participants through the experiments conducted and such mechanisms can be utilized for distancing in the pandemic. In this context, there are recent studies in the literature that promotes HRI models in a variety of fields with the aid of different size and number of robots. The health industry is the primary one in which HRI solutions have been spread through immensely because of the risk factors included. Su et al. (2021) offers to disseminate the use of medical robots for clinical care. The authors highlight the importance of robotic assistance through diagnoses and surgeries to reduce the risk of infection. Thus, the authors argue that an enhanced patient and staff care can be achieved in medical environments with the help of HRI. Similarly, Céspedes et al. (2020) also proposes robot involvement in a more specific health branch, i.e., neurology in which HHIs occur, especially for rehabilitation processes. In their study, the authors offer a robotic assistance for clinical gait rehabilitation with social distancing. Similarly, in the study conducted by Wazir et al. (2021), a different branch of the health industry is offered to collaborate with HRI for dialysis process. The authors propose a mobile dialysis robot, present the hardware components and evaluate its performance in a clinical usage with respect to a set of parameters. In Shen et al. (2021), the authors present a comprehensive survey on the usage of robots during COVID-19 pandemic not only for the health industry, but also in social and commercial fields such as industry, agriculture, education, etc. The authors argue potential robotic capabilities for adaptation of robots in each of these fields. Feil-Seifer et al. (2020) emphasizes the significance of HRI to achieve a safe distance where in-person participants are required, such as laboratory studies conducted in different industries. Moreover, the authors advocate that scientific progress is highly dependent on novel approaches with the help of HRI involvement for the crisis periods such as the one initiated by COVID-19.

The literature so far argues the need of HRI and presents HRI models with area-specific robotic hardware involvement. As well as using specific robot hardware, smartphone oriented HRI solutions especially for social environments also exist in the literature with less infrastructure costs. For example, Chacko and Kapila (2019) proposes to use smartphones for an augmented reality (AR) model instead of costly hardware. The authors accomplish to use smartphone components such as camera, gyroscope sensor, etc. for the cost effective AR model provided in their study. A similar HRI architecture is also constructed by Wu et al. (2020) with the help of personal smartphones. In the study, the authors make an HRI model available for individuals with disabilities. For this purpose, they utilize sensor data of a smartphone and provide a low cost HRI model with environmental adaptability. In Demir et al. (2019), the authors are inspired by the strong attachments between people and their smartphones to provide smartphone oriented HRI applications within the concept of Industry 5.0. The authors argue the opportunities from the organizational perspective as well as the employee perspective to provide innovative HRI solutions. Uddin and Torresen (2019) offers to use smartphone capabilities for an HRI environment in which a prediction model on the activity recognition of an individual is constructed. For this purpose, the authors utilize smartphone sensors and train a machine learning model on the HRI data obtained from these sensors. Considering the literature on smartphone oriented HRI solutions, in this study, we offer to achieve HRI through the use of personal smartphones.

A flexible, fast and robust application stack is required for an HRI solution that has different client applications as proposed in this study. However, the hardware that hosts an HRI client application such as smartphones, wearable devices, etc. consists of a low computational capability. Hence, the burden of computation complexity on the single tenant infrastructure should be alleviated with a proper design. For this purpose, cloud services can be utilized because of the benefits indicated by Kravchenko et al. (2019). The authors conduct a feedback test methodology through a cloud application considering the download speed and the cloud resource usage. They, finally, advocated the effectiveness of cloud technologies, according to the evaluation outcomes. Similarly, Rashid and Chaturvedi (2019) tries to evaluate the performance of cloud technologies, considering the services provided by leading organizations in information technologies such as Amazon, Google and Microsoft. The authors highlight the opportunities and challenges of cloud services considering key performance indicators such as scalability, reliability, cost-effectiveness, etc. for fast, robust and scalable applications. Guerron et al. (2020) also provides a broad taxonomy on key performance indicators of cloud technologies. The authors stated that the performance efficiency is the major performance indicator that is commonly used to evaluate a cloud infrastructure. They also highlighted that a remarkable efficiency gain is possible by using cloud technologies instead of conventional single tenant approaches. There is a set of different cloud service levels studied in the literature to construct a concrete application infrastructure. Shallal and Bokhari (2016) identifies the main service levels as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). The authors present characteristic, services, opportunities and challenges about each of them. Similarly, Odun-Ayo et al. (2018) investigates the main service level of cloud infrastructures as well as hybrid clouds arose form collaboration of different service levels. As a summary, a hybrid cloud infrastructure is constructed in this study to utilize the benefits of cloud services presented in the literature.

In this paper, it is intended to build a pioneering HRI solution for social distancing in daily routines with a proper application stack. Thus, considering the aforementioned motivations on using a smartphone oriented environment for HRI and utilizing cost effective cloud services for application development, we offer the contributions given below:

- We offer to utilize personal smartphones to construct an HRI model so as to reduce HHI interactions causing the spread of COVID-19 in people's daily routine.
- We present an HRI as a Service (HRIaaS) model using a set of cloud services to effectively adapt HRI in our daily life.
- We conduct an experimental case study in an a la carte restaurant as a social environment for daily routine, and we evaluate the proposed HRIaaS model to compare with the old routines according to the number of HHIs.

The rest of the paper is organized as follows: Firstly, the proposed system model for HRIaaS is given in Sect. 2. Then, the case study is introduced and evaluated in Sect. 3. Finally, the study is concluded in Sect. 4.

2 Proposed system architecture

The system architecture of the proposed HRIaaS is given in Fig. 1. There are different types of mobile clients such as mobile phones, tablets, personal computers, and laptops and a cloud environment, including a set of major components such as a cloud infrastructure, cloud services and cloud storage. A data flow can be triggered between client devices and cloud environment in both directions. In this study, IaaS, PaaS, and SaaS are collaboratively utilized to effectively manage the complexity of the proposed HRIaaS model. A mobile application, a web application and related web services are developed for the components in the architecture.

The proposed HRIaaS model has an application stack as stated in Fig. 2. There is an underlying IaaS at the bottom to provide a scalable virtual machine (VM) environment. An operating system (OS) distribution is configured on the VM. There are a database server and an application server set up on the OS. The database server is responsible for data storage and the application server hosts a web API and a web application. The API communicates with the mobile clients for data transfer and the application is for data display and management.

The details of the technologies used in the system architecture is given in Table 1. Firstly, a droplet service, an IaaS, is used in the model provided by Digital Ocean.

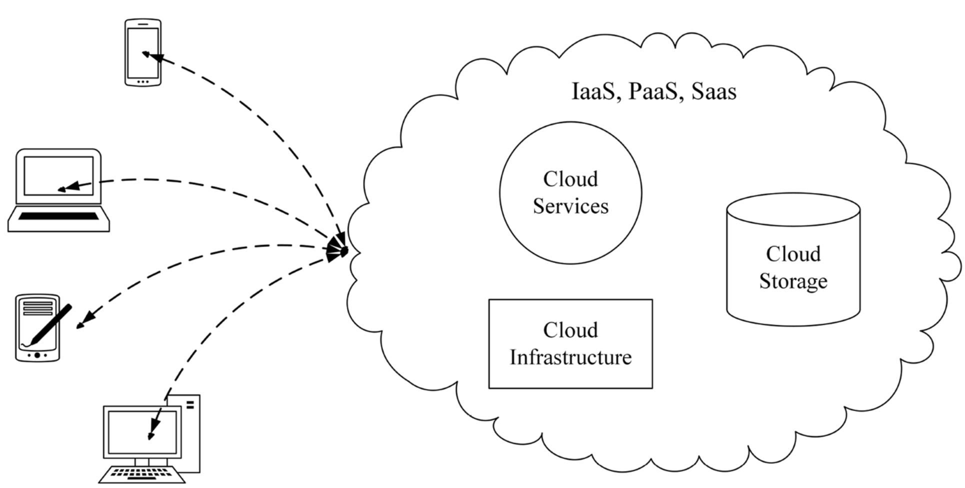


Fig. 1 The proposed HRIaaS architecture

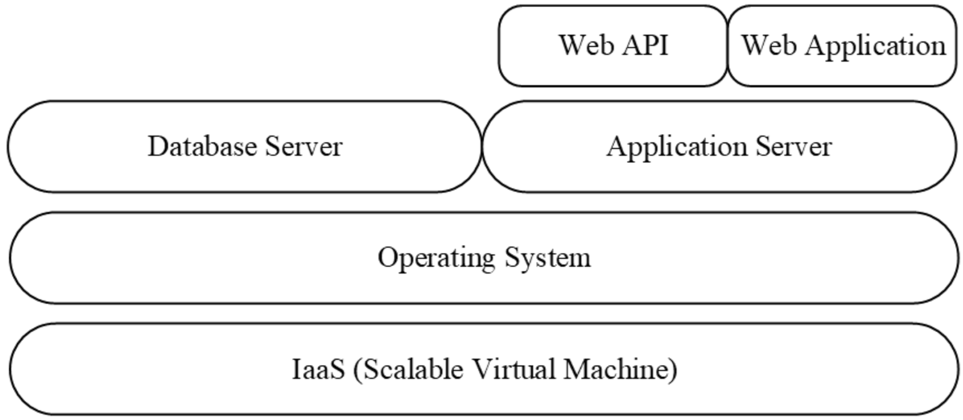


Fig. 2 The proposed HRIaaS application stack

Table 1 Implementation details of the proposed HRIaaS model

Purpose of usage	Name of the technology	Version used
IaaS for a scalable VM infrastrcuture	Digital ocean droplet	Basic version
Operating system for a stable platform and run-time environment	Debian	Release 10
Application server for hosting the web app and the web API	Nginx	Version 1.18.0
Database server for data storage	MySQL	Release 8.0
Software framework for the web app and the web API	.net Core	Version 3.1
SaaS used in case study	Ideal	Version 3.6
	Swagger	Version 3.0.3
	Google Analytics	Version 4

Secondly, to construct a PaaS, Debian operating system is installed on the droplet to host the components of the application stack. Nginx and MySQL are preferred as the application server and the database server, respectively. The web components of the application stack is developed with C# language and .net Core framework, whereas mobile components are developed using the native programming approach for Android and iOS devices. Kotlin programming language with Android SDK and Swift programing language with Cocoa Touch Framework are used for Android and iOS programming, respectively. In brief, a PaaS is obtained on the proposed application stack. Finally, some SaaS components are also used in the HRIaaS architecture such as Ideal, Swagger, and Google Analytics. These components are utilized to enable a remote payment service, to prepare documentation and to keep usage statistics, respectively.

The entire model introduced above has been implemented in four months with the involvement of three senior software developers that are experts on Android, iOS and back-end development. Moreover, one project manager also contributes to the development process by organizing the development team and supporting integration processes. An agile software development approach has been utilized throughout the implementation of each components in the the application stack. For this purpose, software tools such as Jira, GitHub have also been involved in the development process.

3 Evaluation of the model

3.1 Evaluation environment

The evaluation of the proposed HRIaaS is conducted in a real world test bed, i.e., an a la carte restaurant with lunch and dinner services. The evaluation environment is depicted in Fig. 3. There are customers sitting over tables, staff of the restaurant and a set of equipment that runs different client applications with the proposed HRIaaS model in the figure. The configuration of the evaluation environment is also given with Table 2. The capacity of the restaurant consists of 30 tables to serve 80 people, simultaneously. The number of HHIs is first recorded with a conventional order management and payment application for one month period. Then, the proposed HRIaaS model and its application stack is consulted for five consecutive months to trace the number of HHIs.

A sequence diagram for HHI of a customer in the conventional scenario is given in Fig. 4. There are three main flows given in the figure. Firstly, the customer decides on an order and confirms it in steps 1–2. Then, the waiter

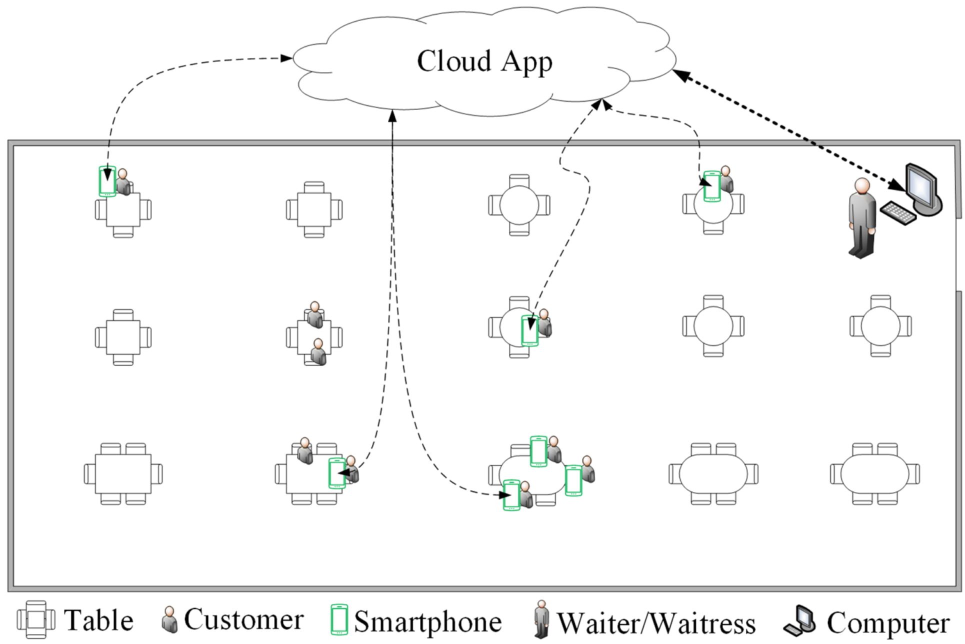


Fig. 3 The illustration of evaluation environment

Table 2 Evaluation environment configuration for the case study

Case study component	Description
Environment	A la carte restaurant
Capacity	30 tables / 80 people
Duration	1 month
Evaluation parameter	Number of total HHI count

delivers the order in step 3 as soon as it is ready. This may repeat several times to add to the order. Secondly, the customer may consult the waiter about a meal, payment, or something else in step 4. This flow is considered as an optional one. Thirdly, the customer makes payment in step 5 with one of the following ways: using a credit card or cash. Hence, the total number of HHIs in an a la carte

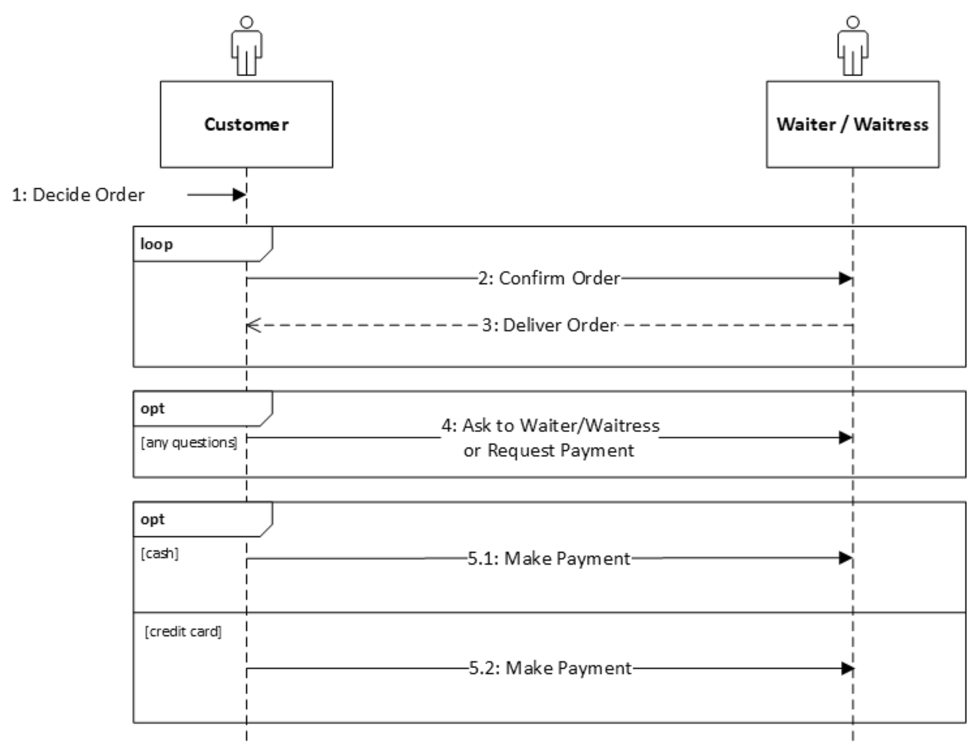


Fig. 4 Sequence diagram for HHI of a customer in the conventional scenario

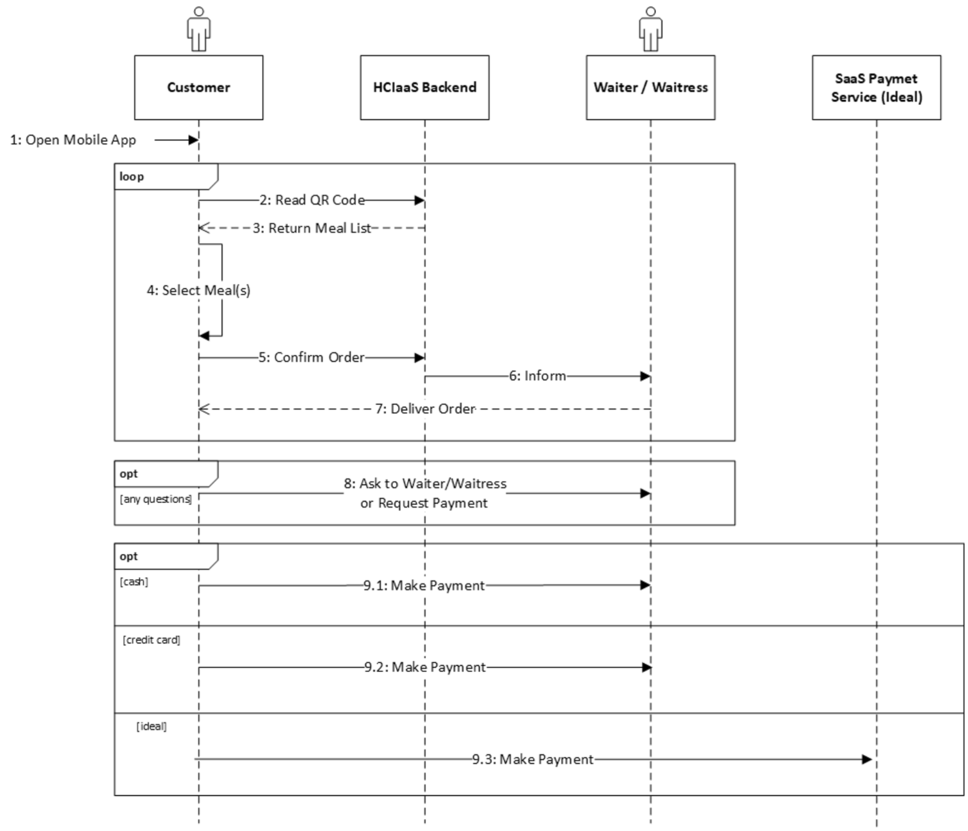


Fig. 5 Sequence diagram for HHI of a customer in the scenario with HRIaaS model

restaurant without HRIaaS is achieved according to the given sequence diagram.

A sequence diagram for HHI of a customer is given in Fig. 5 when the proposed HRIaaS model is used. There are again three main flows in the diagram; however, there are also differences with the flows given in the conventional scenario without HRIaaS. Firstly, the order is made by using the mobile app with a set of steps. The customer reads a QR code through the app, gets the meals list, selects meals and confirm the order in steps 1–5. Then, the HRIaaS back-end informs the staff to prepare the order and the waiter delivers it when ready in steps 6–7. This flow may repeat for additional orders during a lunch/dinner time. Secondly, the customer may consult the waiter as in the conventional scenario in step 8. Thirdly, the customer makes payment in step 9 with an additional option to the conventional scenario: remote payment provided by HRIaaS model. For this purpose, a SaaS named Ideal is collaborating with the proposed system application stack. Consequently, the number of HHIs is again counted for the scenario with the proposed HRIaaS.

There are three different ways of HHI achieved from the experiments explained below:

– HHI to give an order, *(HHI-GO)*, is the interaction in which the staff is consulted to give and to deliver an order;
– HHI to consult about a meal, *(HHI-CM)*, is the interaction in which the staff is consulted about a meal, payment or another issue;
– HHI to make payment, *(HHI-MP)*, is the interaction in which the staff is consulted to make payment with one of the payment methods.

The aforementioned HHI types are considered in the evaluation of each experiment and compared with each other. As a consequence, the effect of the proposed HRIaaS model on the number of HHIs is evaluated.

3.2 Evaluation results

The proposed HRIaaS model is evaluated through the number of HHIs per customer computed in the case study. For this purpose, the total number of HHIs is counted according to aforementioned HHI types named as HHI-GO, HHI-CM and HHI-MP. Moreover, different payment types affecting the number of HHI-MP are also investigated for the

Table 3 The evaluation results in different experiments

Experiments	Total customers	HHI-GO	HHI-CM	HHI-MP		Total HHI	Avg. table occupancy	HHI per customer
Conventional	4338	5687	1422	C CC I	1178 2687 0	10974	48 mins	Baseline
HRIaaS-I	4589	2985	1125	C CC I	937 1217 1602	6866	35 mins	↓41%
HRIaaS-II	4808	3087	1278	C CC I	963 1298 1785	7321	34 mins	↓40%
HRIaaS-III	4358	2817	1071	C CC I	826 1263 1632	6571	35 mins	↓41%
HRIaaS-IV	4287	2724	978	C CC I	768 1276 1723	6251	33 mins	↓42%
HRIaaS-V	4423	2765	898	C CC I	721 1213 1821	6252	32 mins	↓44%

evaluation. Finally, the effect of the proposed model on the average occupancy period of each table in the restaurant, i.e., loosely coupled to the number of HHIs, is also examined.

The performance evaluation of the study is summarized in Table 3. The evaluation outcomes are stated in the rows of the table considering six different experiments; one with the conventional approach and the remaining five with the proposed HRIaaS model. The name of each experiment conducted is given in the left most column of the table. The first row corresponds to an experiment with the conventional ordering and payment approach and is indicated as *Conventional*. Each of the experiments with the proposed HRIaaS model is named with a roman number concatenation as *HRIaaS-I*, *HRIaaS-II*, etc. The roman number specifies the order of experiments with the proposed HRIaaS model, each with one month duration. In each experiment, the total number of customers, total HHI-GO and total HHI-CM counts are presented in the table, from the second left most column to the right, respectively. Moreover, the number of HHIs caused by different payment methods is also detailed in the table because of the fact that the proposed HRIaaS model offers a SaaS for remote payment to reduce HHI. Different payment types are indicated in the fifth column, from the left, as cash (C), credit card (CC), and remote payment with Ideal SaaS (I). The total number of HHIs is also given in the table according to each experiment. Furthermore, the average occupancy period of each table in the restaurant is also examined to provide its relation with the number of HHIs. Finally, the rightmost column of the table shows the reduction ratio on the number of average HHI per customer between the experiments with the proposed HRIaaS model and the baseline scenario in which the conventional model is used. The average HHI per customer is achieved through a normalization process considering the total number of customers and the total number of HHIs because of the fact that they are changing for different experiments conducted each month. As a consequence, an average of 41% reduction in HHI per customer is accomplished by virtue of the proposed HRIaaS that can be noted as a significant amount to fight against the spread of the virus.

The number of HHI-GO per customer is illustrated in Fig. 6 according to the different experiments. HHI-GO refers to the interaction of a customer with a staff in the restaurant to give an order. It can be claimed from the figure that HHI-GO is reduced by almost 50% in HRIaaS experiments, i.e. from *HRIaaS-I* to *HRIaaS-V*, to compare with the conventional one. This is because of smartphone usage in the HRIaaS model to give an order instead of interacting with a staff. Moreover, standard deviation in HHI-GO per customer is also computed through the experiments and indicated with a vertical bar in the figure. The deviation of this parameter is obtained around 2% between different experiments and noted as a convenient value. As a summary, it can be stated that the proposed HRIaaS model has an expressive effect to reduce the number of HHI-GO compared with the conventional approach.

The number of HHI-CM per customer is also illustrated in Fig. 7 according to the different experiments. HHI-CM corresponds to the interaction between a customer and a staff to consult on a meal or something else. The proposed HRIaaS model allows a customer to get information about the ingredients, nutrients, allergens, etc. in a food or beverage

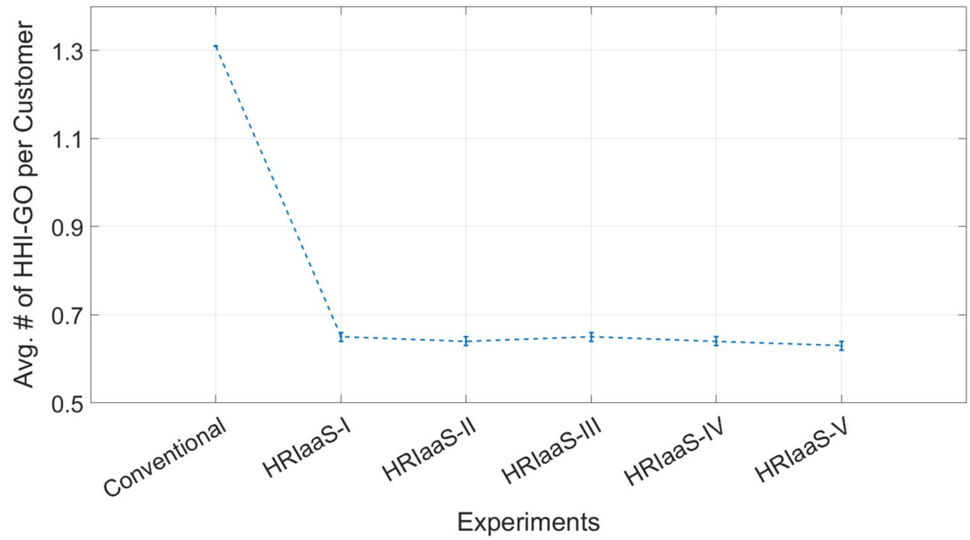


Fig. 6 Average number of HHI-GO per customer in different experiments

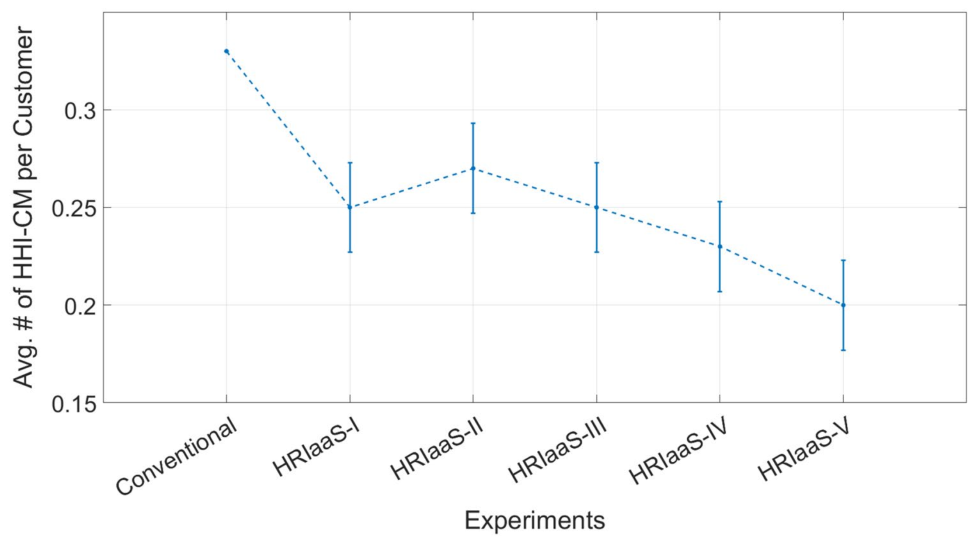
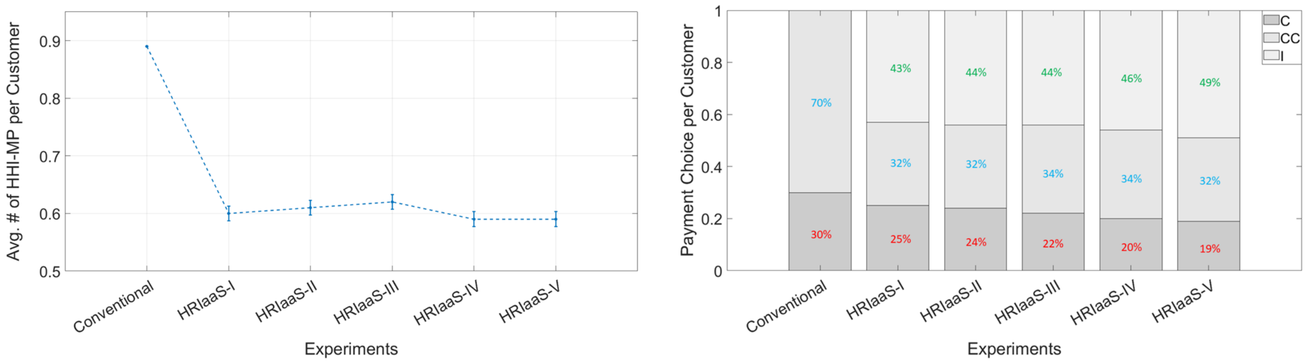


Fig. 7 Average number of HHI-CM per customer in different experiments

through the mobile application in the application stack of the model. Thus, the number of HHI-CM is also reduced about 26% with the deployment of HRIaaS model compared to the conventional approach. It can be claimed that the decrease obtained in HHI-CM is lower than the one in HHI-GO because of the consultation need of a customer not only for a food but also for other issues about the restaurant. Thus, the standard deviation is computed around 9% on this parameter that is apparently higher than the one computed for HHI-GO. The deviation is also depicted on the figure with again vertical bars. As a result, it can be argued that the proposed HRIaaS model produces lower HHI-CM per customer, although the amount of deviation in the experiments is relatively higher than the one in HHI-GO.

The number of HHI-MP per customer and its breakdown to the payment choices are also illustrated in Fig. 8 according to the different experiments. HHI-MP indicates an interaction of the customer with a staff to make payment with one of the three aforementioned payment services. As seen in Fig. 8a, it can be claimed that the number of HHI-MP is reduced to 33% with the usage of the proposed HRIaaS model instead of the conventional approach. The standard deviation on HHI-MP through the HRIaaS experiments are also computed as 3% and indicated in the figure with vertical bars. The decrease on the number of HHI-MP is mainly caused by the remote payment service deployed in the proposed HRIaaS model. It is aimed to further alleviate the interactions between customers and staff by accommodating Ideal remote payment SaaS. As seen from Fig. 8b, the ratio of Ideal payment choice accounts for almost half of the total number of payments in the HRIaaS experiments. On the other hand, although credit card payment is preferred more often in the experiment with the conventional approach, both cash and credit card payment types require HHI through the



(a) Average number of HHI-MP per customer

(b) Payment choice per customer

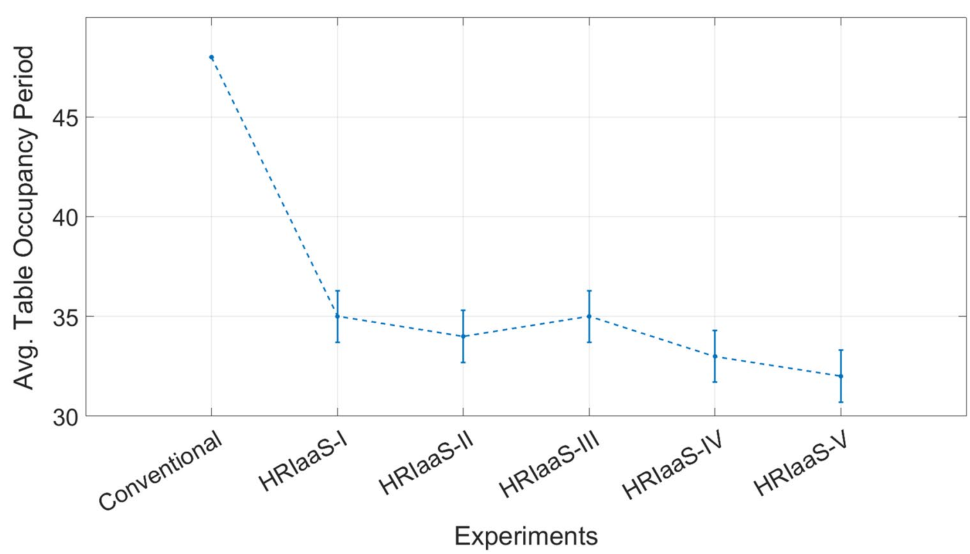
Fig. 8 Average number of HHI-MP and distribution of payment choices in different experiments

payment process. In summary, it can be asserted that using a remote payment SaaS is an effective way to reduce HHI by in the proposed HRIaaS model and the evaluations on HHI-MP are obtained as expected.

The average occupancy period of a table in the restaurant, that has a coupling between number of HHIs, is also investigated through the experiments in the case study. The evaluation results of the average occupancy period are given in Fig. 9. It can be seen from the figure that there is 29% decrease for this parameter when the experiments with the conventional approach and with the proposed HRIaaS model are compared. A standard deviation of 3% is also noted between different experiments with HRIaaS model that can be seen as acceptable for the statistical validation of the case study. A correlation between average table occupancy period parameter and HHI-(GO,CM,MP) parameters can be inferred from the evaluation results. This correlation can be stated as expected and validates the evaluation of different experiments. In short, it can be advocated that the proposed HRIaaS model leads to less table occupancy period for eating in the restaurant and promote social distancing from this perspective.

As a consequence, according to the evaluation outcomes, it can be claimed that the proposed HRIaaS model is strictly able to reduce HHI-GO and HHI-MP compared with the conventional model without any HRI. On the other hand, the proposed model also capable of reducing HHI-CM with a higher deviation. Nonetheless, the average number of HHIs per customer is reduced around 41% and it can be claimed that it is a decent amount for COVID-19 prevention contributed by social distancing in people daily routine. Finally, it can be claimed that the proposed HRIaaS model promotes social distancing as a result of the evaluation outcomes presented.

Fig. 9 Average table occupancy period in different experiments



4 Conclusion

There has been an immense struggle all over the world since the COVID-19 pandemic began. The prevention strategies are seen as the most effective way to overcome the spread of the disease. For this purpose, various technological disciplines are consulted to adapt the daily routine of people to the pandemic era. In this study, we put forth the social distancing as the strongest weapon for combating COVID-19 and offer a cloud-based HRI model named HRIaaS exploiting individual smartphones to reduce HHI in daily life. For this purpose, an IaaS is utilized; a PaaS is constructed and deployed by collaborating other SaaS services. A case study including six different experiments in an a la carte restaurant is introduced and examined with the proposed HRIaaS model as well as a conventional model without any HRI. The total number of HHIs considering different types of HHIs, average occupancy period of a table in the restaurant and HHI per costumer are computed through all experiments. Finally, the evaluation results are presented and interpreted. According to the results, it can be asserted that social distancing is obtained between a customer and a staff considering different interaction types. An average of 41% decrease is achieved in the number of HHIs per customer by using the proposed HRIaaS model in the case study. As a conclusion, the evaluation of the proposed HRIaaS model shows that a remarkable reduction for the number of HHIs is achieved in social environments people involved as a daily routine. We believe that this work has a satisfying HHI prevention during the pandemic process and can also be exploited for a similar solution in different problem domains not only during the pandemic but also for the post pandemic era.

As a future work, it is aimed to deploy the proposed HRIaaS model on different scale and scope of industrial and educational domains to encourage social distancing in different areas of daily routine. Thus, new case studies are planning to be prepared for the evaluation and validation of the proposed model. Moreover, the evaluation of the proposed HRIaaS model is planned to be extended considering the customer satisfaction in such service-oriented environments. For this purpose, the Queuing Theory are planning be applied to have model on average waiting time, average service time, etc. Hence, the quality of experience obtained from the proposed HRIaaS model is aimed to be measured and compared with a conventional approach.

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