Spatial-Temporal Database Based Asynchronous Operation Approach of Fruit-Harvesting Robots

Bin Zhou, Liang Gong, Qianli Chen, Yuanshen Zhao, Xiao Ling, and Chengliang Liu(✉)

Department of Mechanical and Electronic Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
{zhou_bin,gongliang_mi,chenqianli,lingxiao,chlliu}@sjtu.edu.cn

Abstract. Autonomous fruit-harvesting robots encounter difficulties of low fruit recognition rate and picking efficiency due to the complex unstructured operational environment. To solve this problem, an asynchronous approach has been proposed to discriminate the recognition and manipulation process. The fruit recognition task can be intensified via repetitious inspection or human-robot interaction, meanwhile a spatial-temporal database is constructed to record the recognition information which might facilitate the sequential picking manipulation. In this paper the attributes of a spatial-temporal object are firstly investigated with four elementary constituents attached. Hereby the fruit target is modeled for harvest decision-making. Secondly a three layer database management system is designed as per the modular design principles. Finally, we introduced a picking scheduling application based on this database management system. The picking schedule demonstrates that the Construction of the spatial-temporal database paves the way for the success of paradigm shift from synchronous to asynchronous manipulations of fruit-harvesting robots.

Keywords: Spatial-temporal database · Fruit-harvesting robot · Asynchronous · Intelligence fusion

1 Introduction

Since Prof.kawamura, Kyoto University[1], originated the studies of Autonomous Fruit Picking Machine (AFPM) with a tomato harvesting robot three decades ago, the components of the first fruit harvesting robot were not so quite different from current harvesting robots under development at universities and research institutes. Under the consequence that robots now can be equipped with more powerful computers, cameras with more pixels and sensors with smaller volume, their success rate and operating speed are still far from our satisfactory[2 3]. The reason is mature fruit's recognition, match and location ability, the fruit-harvesting robot's primary ability, has been restricted under complex outdoor environment or greenhouse condition. And exactly, that's what human-beings really good at. As a consequence, a semi-autonomous fruit-harvesting robot

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system can be a good solution help to limit costs and guarantee a high degree of reliability [4].

Autonomous mobile robot equipped with can collected spatial and temporal data [5 6]. In this system, robot is designed as two arms for multi-task through replacing different executing ends. The head is a binocular Camera which can obtain 3D information of the environment. IPC controls the robot and exchanges information and commands with both mobile devices and server. Recognition and location are synchronous work, which mainly executed by human on mobile devices or PC. The picking action is asynchronous carried out by end-effector, and should be arranged by relative space position of robot and mature tomatoes. In this consequence, the key technology is a data management system, which can handle fruit's temporal and spatial information at the same time after a pretreatment of data gathered by both binocular camera and HRI.

This asynchronous approach mentioned above combines human's advantage in recognition and robot's advantage in executing, trying to asynchronous manipulating between perception, strategy and picking action to improve fruit-harvesting robots' performance in complicated outdoor environment. In this study, we focus on the construction of a spatial-temporal database management system for the asynchronous operation of target recognition and picking.

2 Design of Spatial-Temporal Database

Spatial-temporal databases deal with objects that change their location and/or shape over time by recording their spatial and temporal information [5]. Effective database analyzing applications tracking these changes could be a support for strategy- making [6].

2.1 Spatial-Temporal Object

Spatial-temporal databases are generally used in GIS. It is the key technology of managing subjects that changing over time in space or shape features. Four elementary constituents should be specified in a spatial-temporal object: position, descriptive attributes, spatial attributes and temporal attributes (Figure 1) [7].

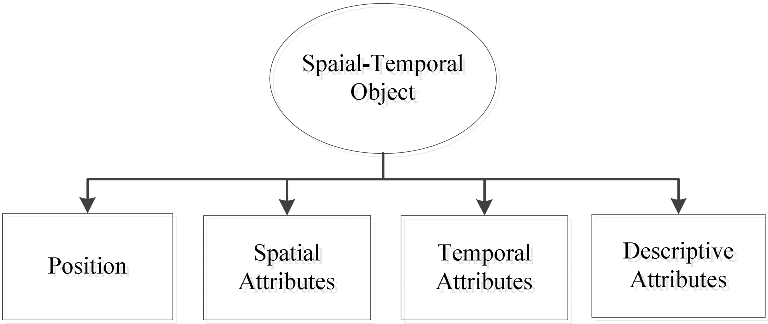

Fig. 1. Spatial-temporal Object

- Position

Position represents spatial location of an object, which can be expressed in form of (x, y, z). Target position is the key attribute and can be recorded through coordinate system transformation.

- Spatial Attributes

Spatial attribute is location-related which inherited property from the spatial position. Enumerated data type (0-pick_enable, 1-pesticides_need, and 2-seed_regeneration) can used to express a spatial attribute, so as to take environment aspects into consideration.

- Temporal Attributes

Temporal attributes are appended to identify inputting time (the first time one object being observed) and observing time (a refresh of the nearest observed time) of the object. Each time attribute can be recorded as the form of bellowing:

DD：HH：MM：SS

- Descriptive Attributes

Descriptive attributes label other attributes of one object, which is user-defined and extensible. For instance, the maturity is an important attribute of fruit and should be recorded into database.

2.2 Basic Modules of Spatial-Temporal Database

We design a three-layer structure for the whole data management system (Figure 2), which can be broken into 6 modules.

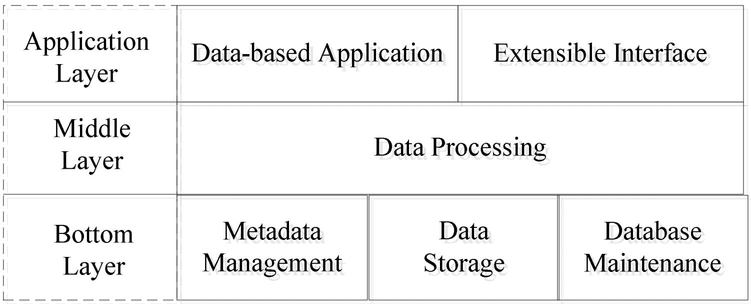

Fig. 2. Three-layer structure of spatial-temporal database

Bottom Layer

- Meta-data Management

We describe data structure, file system and data association by using meta-data standards specific to a particular discipline. Meta-data is data about data. By describing the contents and context of data files, the usefulness of the original data/files is greatly increased.

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<! DOCTYPE spatial-temporal DATABASE "std">
<std>
<!--DATA STRUCTURE--!>
<table name="table_target">
  <list id="id">ID</list>
    <list id="x">X</list>
  <list id="y">Y</list>
  <list id="z">Z</list>
  <list id="input_data">INPUT_DATA</list>
  <list id="refresh_data">REFRESH_DATA</list>
  <list id="area">AREA</list>
  <list id="picked">PICKED</list>
  <list id="discribe">DISCRIBE</list>
</table>
<table name="table_picture">
  <list id="id">ID</list>
    <list id="x">X</list>
  <list id="y">Y</list>
  <list id="z">Z</list>
  <list id="input_data">INPUT_DATA</list>
<picture>url</picture>
</table>
<!--DATA ASSOCIATION--!>
<link name=″link1″ description=″″ >
<from >......</from>
<to>......</to>
</link>
.....
</std>
```

- Data Storage

We store data with two dimensions: temporal dimension and type dimension (Figure 3).

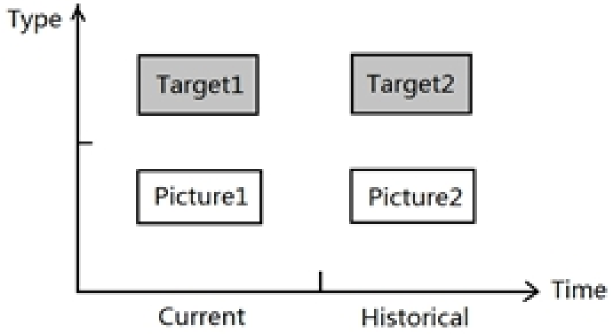

Fig. 3. Storage Dimensions

The temporal dimension consists of historical data, which is data of tomatoes that has been picked, and current data. Robot can learn from past data to generate new levels of intelligence with the help of machine learning algorithms.

Type dimension expresses two different data types stored in database: picture (Table 1) and target (Table 2).

Table 1. Picture Data Type

ID	X	Y	Z	DIRECTION	DATE	DATA
picture1	..	..	..	..	..	..

Picture data is constituted with location data where robot takes it, direction data of the robot, time data when robot takes it and image url. It is the primary data we get from the binocular camera.

Table 2. Target Data Type

ID	X	Y	Z	DATE1	DATE2	DISCRIBE	PICKED
target1	..	..	..	..	..	..	..

As a spatial-temporal object, target data structure involved all four elements as shown in Table 2.

- Database Management

Spatial-temporal database's function of management mainly includes following aspects:

1. Database security management and user management;
2. Copy or Delete operation of spatial-temporal database;
3. Data Import and Export.

Middle Layer

This layer contains all data processing procedures just exampled as below:

- Data Preprocessing

Data preprocessing generate target data according to picture data and human-robot interaction results. The first step is extracting the pixels of tomato, which can be determined by human click or touch, and calculate average depth of these pixels to get the relative position of robot and the target (Figure 4). Then we can get the position of target in the greenhouse space through coordinate system transformation.

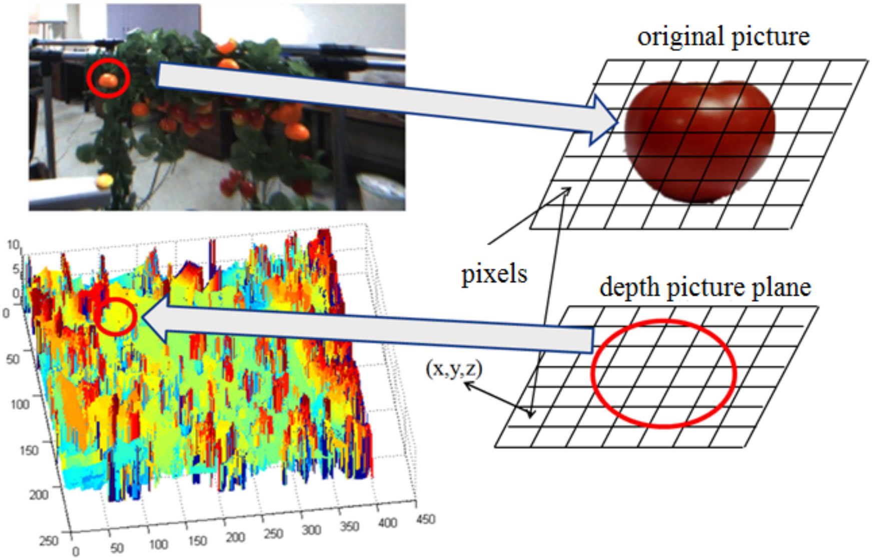

Fig. 4. HRI

- Data Compression

Image data need to be compressed before stored into database as the data size is 1M each.

- Data scrubbing

Data scrubbing maintains the cleanliness of database. When a target has been picked, the data of this target should be transferred to historical database.

Application Layer

- Application

Based on the spatial-temporal database platform and data processing algorithms, plenty of applications can be developed according to customer's requirement. These applications are modular designed and aiming at specific mission.

- Extensible Interfaces

Except applications, we will provide enough interfaces for customers who don't want to make sense of how the data is generated and processed to develop an application.

3 Picking Scheduling Based on Spatial-Temporal Database

The whole system is makes up of five independent small systems (Figure 5):

— Visual information collection system (**S1**);
— Robot gesture and location collection system (**S2**);
— HRI system (**S3**);
— Motor system (**S4**);
— Spatial-temporal database management system (**S5**).

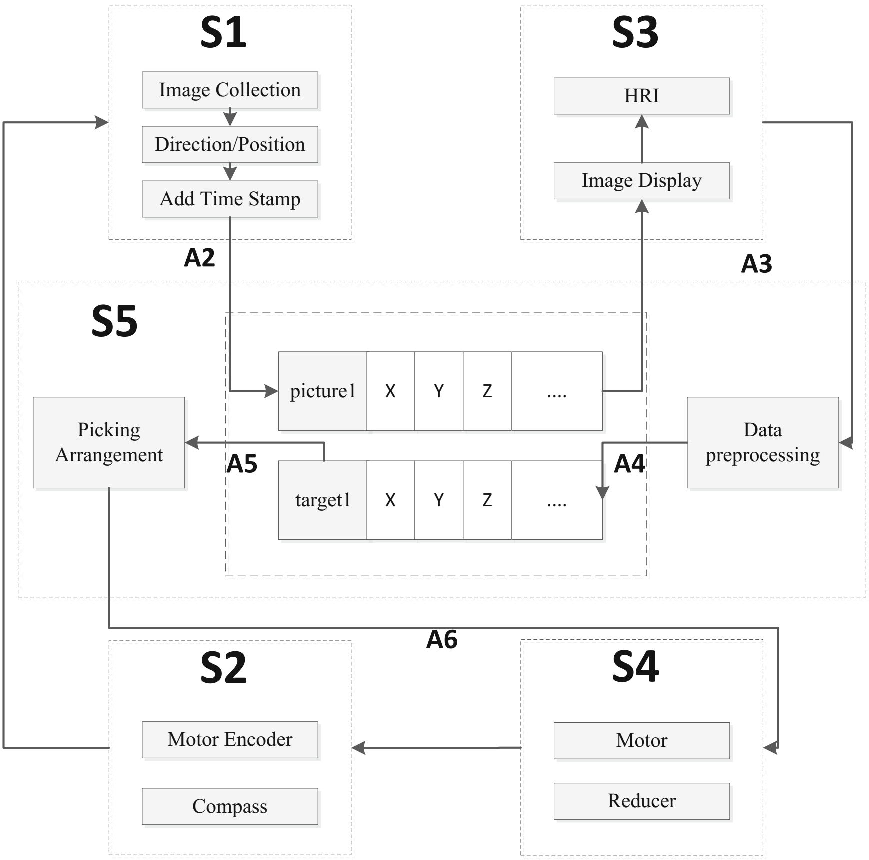

Fig. 5. The diagram of picking arrangement

To applicate a picking scheduling task, five systems cooperate as following steps:

- **A1:** When robot reaches one fixed position, S2 records gesture and location of robot at this moment and then sends this information together with a time stamp to S1.
- **A2:** S1 receives the time stamp as an initiator for binocular camera to capture a picture contains depth information. Then a package together with picture, position, time and direction will be send to S5. S5 unpacks the package, compresses the picture and stores all the data to Table1.
- **A3:** S5 arranges image displaying in terminals (PC or mobile devices) in regard with terminal state and robot location. S3 sends plane coordinate values that generate by human click or touch to S5.
- **A4:** S5 preprocesses the data send by S3 to get target position. After a contrast with existing data, S5 decides whether create a new target or refresh the existing data.
- **A5:** If qualified data reach a given scale, S5 will make a picking schedule in regard with robot location and target position in a scheduling time.
- **A6:** S4 receives the arrangement and start a picking action. Between robot movements, fixed position being stroked one by another, then we return back to step A1 and forms a closed loop.

4 Conclusion and Future Work

4.1 Conclusion

In this study, we proposed a method for human-robot cooperation fruit harvesting, which is asynchronous both in spatial and temporal. In this method, a spatial- temporal database management system is designed to support picking strategy formulating, task scheduling and other appropriate applications of data, and as we can see in the picking scheduling application, this database management system act as the brain of the whole system. The final system is under test, which has not yet achieved a level of productivity capable of replacing human pickers. Further mechanical modifications and more robust and adaptive algorithms are needed to achieve a stronger robot system.

4.2 Future Work

More software Tools should be developed to help robot mining effective information from these data. An intelligence robot can extract information from its environment and make decisions without the help of humans. To achieve this goal, an ideal effect we want to realize is that robot can get the knowledge of how human recognize tomato, which can be integrated with feature extraction of images. In this consequence, besides improving the mechanical condition, we will imply more machine learning and pattern recognition algorithms to this study.

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