

Title of invention: Tool storage system with programmable array of sensors

FIELD

5 [001] The present invention relates to a tool storage system with a programmable array of sensors.

BACKGROUND

10 [002] Typically, tools are stored in a drawer in a tool cabinet. An inventory control system is then needed to monitor the removal and return of tools to the cabinet.

[003] Existing monitoring methods include using a RFID tag attached to the tool. However, RFID tags may drop off after a period of wear and tear.

15 [004] To circumvent such wear and tear, a non-RFID approach uses camera and vision with learning capabilities. In one implementation, a drawer is illuminated by an internal light source when drawn open so that a camera can detect a tool that is being removed or withdrawn. Such an approach is sometimes denied inside military facilities because product or equipment equipped with camera technology is perceived to have potential risk of information leakage.

[005] Tracking using weight sensing is another approach. However, it has low reliability.

20 [006] The present invention seeks to address the above shortcomings.

SUMMARY OF THE INVENTION

[007] According to a first aspect of the present invention, there is provided a tool storage system including a board with an array of sensors, each configurable to be reserved for tool storage or vacant; 25 a decoder to monitor usage of the array of sensors; a remote terminal to process signals received by the decoder, the remote terminal configured to: learn a location of the reserved sensors and the vacant sensors from the signals received during initialisation of the board; receive input providing details of the tool stored on the reserved sensors; detect, from the signals when the board is used, for removal of tools from and return of tools to the reserved sensors; and determine whether to transmit a message that 30 a wrong tool is returned when the decoder relays that at least one of the reserved sensors is triggered incorrectly during the tool return; and a data storage to save details of the tool stored by the reserved sensors, the location of the reserved sensors, and the location of the vacant sensors.

BRIEF DESCRIPTION OF THE DRAWINGS

35 [008] Representative embodiments of the present invention are herein described, by way of example only, with reference to the accompanying drawings, wherein:

- [009] Figure 1 shows components of a tool storage system in accordance with one embodiment of the present invention.
- [010] Figure 2 is an isometric view of a tool cabinet having drawers used to hold the board used in the tool storage system of Figure 1.
- 5 [011] Figure 3 shows return of an incorrect tool to the board of the tool storage system of Figure 1.
- [012] Figure 4 shows the board of the tool storage system of Figure 1 configured to store various tools having different sizes and profiles.
- [013] Figure 5 shows a cross section view of one of the stored tools in Figure 4.
- [014] Figure 6 shows the tool storage system being used with peripheral storage.
- 10 [015] Figure 7 shows a flowchart when tools are drawn from the board of Figure 1 and placed into peripheral storage.
- [016] Figure 8 shows a flowchart when tools are returned to the board of Figure 1 from peripheral storage.
- [017] Figure 9 shows a flow chart for board initialisation.
- 15 [018] Figure 10 shows a flow chart for removal and retrieval of tools from an initialised board.
- [019] Figure 11 depicts components of the remote terminal of the tool storage system of Figure 1
- [020] Figure 12 shows a foam cutout resting on the array of sensors of the board of the tool storage system of Figure 1.
- [021] Figure 13 shows examples of sensors for the board shown in Figure 2.

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DETAILED DESCRIPTION

- [022] The present application relates to a tool storage system which stores tools. Tools refer to instruments used for a particular purpose, such as to service and maintain equipment like machine components. The tool tracking system includes a tool cabinet, which in one implementation, has multiple drawers. Each drawer has a sensor array layer on which a cut-out layer lies. The cut-out layer serves to hold tools in place on the sensor array layer, with each cut-out correspondingly shaped to the tool it holds. The sensor array layer serves to detect presence or absence of tools at their cut-out locations.
- 25 [023] The tool storage system also monitors tool removal and return. Besides guarding against tools being lost or stolen, tracking tool movement is important during several use instances, like ensuring all tools removed are returned immediately after the completion of a task. When repairing or maintaining aircraft engines, any tools left inside the engine after completion of the job could cause catastrophic damage. Similarly, in the case of surgical tools, it is essential to ensure that no tools are left inside a patient after an operation. As for customised tools (such as those to service aircraft components),
- 30 monitoring facilitates their accountability since they may be expensive and difficult to replace.
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[024] The sensor array layer is programmable during initialisation where the tool storage system learns the tools that the sensor array layer is to monitor and the location of the tools on the sensor array layer.

[025] During initialisation, sensors in the array of sensors will be assigned to be either reserved for tool storage when in use; or kept vacant when in use. Vacant sensors refer to sensors that, in use, are unoccupied by a tool. Reserved sensors refer to sensors, that in use, are kept aside for tool storage, although not necessarily being in contact with the stored tool. Reserved sensors can be in an activated state or a null state. In the activated state, sensors are programmed to detect for tool presence or absence during tool return. In the null state, sensors remain silent and do not send a signal, regardless of tool presence. Both the activated state and the null state are described later in greater detail.

[026] When learning is automated, initialisation includes a tools training stage, where tools are placed on a board with the array of sensors and an algorithm determines tool location placement, along with the number and arrangement of adjacent sensors that is needed to accommodate each tool shape, for example, by detecting which sensors are in contact with a tool. The algorithm will memorize both the location and number of sensors that need to be reserved to monitor each tool, based on the shape of the tool on the array of sensors during initialisation. The algorithm will also memorise the location of the vacant sensors. The tools training stage thus allows the location of tools to be automatically learnt after tools are placed on the array of sensors.

[027] When learning is done manually, initialisation has a user entering co-ordinates of reserved sensors and vacant sensors. In contrast with the automated approach, initialisation by the manual approach does not require for tools to be placed on the array of sensors.

[028] Accordingly, the sensor array layer is particularly adapted to store customised tools since they may not fit into a cut-out layer with generic cut-out shapes. Programmability of the sensor array also imparts flexibility by allowing the location of tools (both customised and generic) to be tailored by the user being able to specify their desired locations, by way of detection through placement (in the automated initialisation approach) or inputting of storage co-ordinates (in the manual initialisation approach). The location of the tools on the sensor array may also be changed as required through re-programmed the sensor array.

[029] A message that a wrong tool is returned may be transmitted when one or more of the reserved sensors are found to incorrectly trigger during the tool return. Triggering refers to how a reserved sensor reacts during tool return. Reserved sensors are triggered correctly or incorrectly depending on whether they are designated (as part of the above mentioned initialisation) as activated to expect tool presence or absence during tool return. The reserved sensor will incorrectly trigger if during tool return the reserved sensor returns a status that is contrary to its designation during initialisation (i.e., whether programmed to expect tool presence or tool absence during tool return) because the reserved sensor detects an unexpected outcome. Various scenarios of tool return are described in greater detail below.

[030] The algorithm that determines tool location placement or a separate algorithm allows for the reserved sensors to be rearranged, with the rearranged reserved sensors still being able to monitor a tool. For example, after initialisation, the algorithm may activate most of the reserved sensors falling within or around a boundary of a tool shape (for example, a rectangle) to store the tool. After a predefined period, the algorithm may rearrange the activated sensors such that there may be less or more activated sensors. Alternatively, there may be the same number of activated sensors after rearrangement, but their layout is different compared to before rearrangement, although there may be overlap between the activated sensors in a subsequent layout and the previous layout. The purpose of allowing for such re-configuration is to prevent attempts at deriving the combination of sensors whereby placing a wrong tool could then deceive the array of sensors that the correct tool has been returned. During re-configuration of the sensor layout, a boundary containing the reserved sensors and the location of the boundary remains the same.

[031] Various embodiments of the tool storage system in accordance with the present invention are now described with reference to the drawings, where like reference characters generally refer to the same features across the drawings. It will be appreciated that the tool storage system may have more components that are not described for the sake of simplicity.

[032] Turning to Figure 1, the tool storage system in accordance with one embodiment of the present invention has the following components: a board 100 with an array of sensors 104; a decoder 106 and a remote terminal 108.

[033] The decoder 106 is in electrical communication with the board 100, for instance through a physical or wireless connection. Similarly, the remote terminal 108 is in electrical communication with the decoder 106, through a physical or wireless connection. The decoder 106 acts as an interface to facilitate communication between the board 100 and the remote terminal 108. For instance, the decoder 106 relays signals from the board 100 to the remote terminal 108 on the usage of the array of sensors 104. The decoder 106 can also be used to adjust the sensitivity of each of the sensors 104, such as whether a sensor 104 reading meets conditions to indicate a tool is present. The remote terminal 108 processes signals received by the decoder 106, whereby the remote terminal 108 is used to control the operation of the array of sensors 104 through the decoder 106 (e.g., through hosting an algorithm used to program the array of sensors 104). The decoder 106 may be integrated with either the board 100 or the remote terminal 108; or is a separate component in another embodiment of the invention.

[034] The board 100 may be placed in a drawer 202 of a tool cabinet 200. Figure 2 is an isometric view of such a tool cabinet 200. The tool cabinet 200 may have several drawers 202, with one of more of the drawers 202 carrying the board 100. The tool cabinet 200 has a computing terminal 108 which can serve as the remote terminal of the tool storage system. Accordingly, the remote terminal of the tool storage system may be housed together with the board 100 and need not necessarily be separately or remotely located.

[035] The embodiment of Figure 1 uses a board 100 with a 14 by 11 array of sensors 104 although other dimensions (not shown) are possible. Each of the sensors 104 is configurable to be reserved for tool storage or kept vacant.

[036] As mentioned above, the plurality of sensors 104 is either configured:

- a) to be reserved for tool storage (i.e., referring to sensors 110 that when in use are kept for tool storage). Since tools occupy space, a plurality of adjacent sensors is typically reserved for tool storage. In one approach, more sensors are reserved for tool storage than required. For example, a 6 by 6 sensor array area may be reserved for a tool that only requires a 4 by 4 sensor array space. Accordingly, reserved sensors 110 need not necessarily be in contact with the tool they are kept aside to store; or
- b) to be unoccupied / vacant (i.e., referring to sensors 112 that when in use are unoccupied by a tool).

[037] The remote terminal 108 learns the location of the reserved sensors 110 and the vacant sensors 112 during initialisation of the board 100, for example, from the signals received from the decoder 106 board through placement of tools on the board 100. With reference to the description for step 908 in Figure 9 below, the letter “y” refers to status lights for the board 100 turning yellow to indicate that the board 100 is learning the shape of the tool 116. In another approach, the remote terminal 108 learns the location of the reserved sensors 110 and the vacant sensors 112 by a user entering their co-ordinates during initialisation.

[038] When reserved for tool storage, the sensors 110 can be in an activated state or a null state. In the activated state, the reserved sensors 110 are programmed to detect for tool presence or absence during tool return. Tool presence occurs when the reserved sensor 110 detects contact with a part of the returned tool 116. Tool absence occurs when the reserved sensor 110 does not detect contact with any part of the returned tool. Each activated sensor may further be either in a positive logic state or a negative logic state.

[039] Activated sensors in the positive logic state are configured to expect tool presence during tool return i.e., there is contact with a part of the returned tool 116 during tool return. If such a positive logic state sensor does not detect tool presence during tool return, it will send an error signal. However, if the sensor detects tool presence during tool return, it will not send an error signal.

[040] Activated sensors in the negative logic state are configured to expect tool absence during tool return, i.e., there is no contact with a part of the returned tool 116 during tool return. For example, sensors 114 that fall beyond the perimeter of the tool 116 on the board 100 may be designated as negative logic state sensors. Other examples are sensors that parts of the tool 106 when lying flush on the board 100 do not contact (see Figure 5), whereby these sensors still fall within the perimeter of the tool 106 on the board 100. If the negative logic state sensor detects tool presence during tool return, it will send an error signal. However, if the sensor does not detect tool presence during tool return, it will not send an error signal.

[041] In the null state, sensors are dormant or unresponsive and maintain silence regardless of tool presence or absence. Null state sensors do not send a signal if a tool 106 is present during tool return. They also do not send a signal if a tool is absent during tool return.

[042] The board 100 is ready for use (i.e., in a state to monitor for tool 106 return) after initialisation.

5 The remote terminal 108 detects, from the signals sent from the decoder 106 when the board 100 is in use, for removal of tools 106 from and return of tools 106 to the reserved sensors 110.

[043] If the reserved sensor 110 expects tool presence and detects tool presence during tool return (i.e., part of a tool 106 is detected during tool return), the reserved sensor 110 will be triggered correctly. The decoder 106 will send a signal that the reserved sensor 110 is triggered correctly. If the reserved

10 sensor 110 expects tool presence but detects tool absence during tool return (i.e., no tool is detected during tool return), the reserved sensor 110 will be triggered incorrectly. The decoder 106 will send a signal that the reserved sensor 110 is triggered incorrectly.

[044] Similarly, if the reserved sensor 110 expects tool absence and detects tool absence during tool return (i.e., no tool is detected during tool return), the reserved sensor will be triggered correctly. The

15 decoder 106 will send a signal that the reserved sensor 110 is triggered correctly. If the reserved sensor 110 expects tool absence but detects tool presence during tool return (i.e., part of a tool is detected during tool return), the reserved sensor will be triggered incorrectly. The decoder 106 will send a signal that the reserved sensor 110 is triggered incorrectly.

[045] The remote terminal 108 determines whether to transmit a message that a wrong tool is returned

20 when the decoder 106 relays that at least one of the reserved sensors is triggered incorrectly during the tool return. In one configuration the tool storage system transmits the message that the wrong tool is returned when at least one of the reserved sensors 110 is found to trigger incorrectly during the tool return. However, in another configuration, detection of at least one incorrectly triggered reserved sensor 110 need not automatically result in the transmission of an error message. In this other configuration,

25 the message that the wrong tool is returned only transmits if certain criteria are met in respect of the reserved sensors 110 triggering incorrectly. Examples of this criteria include: the number of incorrectly triggered reserved sensors 110 exceed a threshold (such as three or more); or the incorrectly triggered reserved sensors need to be at a particular location (such as the middle of the monitored tool 106). Accordingly, the remote terminal 108 does not necessarily transmit a message that a wrong tool is

30 returned as long as the remote terminal 108 detects that any of the reserved sensors 110 is triggered incorrectly.

[046] During tools training / board 100 initialisation which is in accordance with an automated approach, tools (Figure 1 only shows one tool 106 for the sake of simplicity) are laid across the board 100, spaced apart. The decoder 106 communicates with the sensors 104 to learn which of them detect

35 a tool thereon (i.e., are in contact with a tool) to determine which are the ones to be reserved for tool storage; and which are unoccupied / vacant. As an alternative to learning through tool placement, the sensors 104 may be manually reserved for each tool 106, where co-ordinates for the reserved sensors

110 and the vacant sensors 112 are provided through the remote terminal 108, where it is optional for the tools to be present on the sensors 104.

[047] Regardless of which approach is used during tools training / board 100 initialisation, the decoder 106 programs the reserved sensors 110 to have one or more sensors in the activated positive logic state; the activated negative logic state; and / or the null state. The algorithm used for such sensor designation may be the same as the one used for automatic board 100 initialisation or a separate algorithm.

[048] For example, in a first algorithmic implementation, all the reserved sensors 110 are in the activated positive logic state, so that the decoder 106 transmits an error message if any of these sensors 110 detect absence of a tool during tool return. In a second algorithmic implementation, some of the reserved sensors 110 are in the activated positive logic state, while a remainder of the reserved sensors 110 are in the activated negative logic state. The decoder 106 transmits an error message if any of the sensors 110 in the activated positive logic state detect absence of a tool during tool return or any of the sensors 110 in the activated negative logic state detect presence of a tool during tool return. In a third algorithmic implementation, a first group of the reserved sensors 110 are in the activated positive logic state; a second group of the reserved sensors 110 are in the activated negative logic state; and a remainder of the reserved sensors 110 are in the null state. The decoder 106 transmits an error message if any of the sensors 110 in the activated positive logic state detect absence of a tool during tool return or any of the sensors 110 in the activated negative logic state detect presence of a tool during tool return. The decoder 106 will not receive a signal from the sensors 110 in the null state.

[049] The remote terminal 108 then saves the location of each set of reserved sensors 110 to demarcate an area of the board 100 set aside for tool storage. Details of the tool 116 stored on the reserved sensors 110 are input into the remote terminal 108, for example by indicating the type of tool / part number stored by each set of reserved sensors 110. In one approach, this may be achieved by a user entering the tool type / part number that was placed on each location on the board 100. In another approach, the remote terminal 108 may automatically assign the tool type / part number by mapping the activated sensors against a tool database. Other details include weight of each tool 116 which is used to monitor tools kept in peripheral storage, described in further detail below with respect to Figures 6 to 8.

[050] A data storage 120 saves the details of the tool 116 stored by the reserved sensors 110, a location of the reserved sensors 110, and the location of the vacant sensors 112. The data storage 120 may be integrated with the remote terminal 108 or separately located, such as realised through cloud storage.

[051] When in use (i.e., after tools training / board 100 initialisation), the decoder 106 assesses whether the correct tools are being returned to their assigned storage spaces. This is achieved by the decoder 106 determining whether activated sensors within the sensors 110 reserved for tool storage are triggered correctly, such as when none of the sensors 110 in the activated positive logic state transmit a signal that a tool is absent and none of the sensors 110 in the activated negative logic state transmit a

signal that a tool is present. That is, the decoder 106 receives a correct signal (that a tool is detected) from sensors 110 programmed to detect for tool presence during tool return; and a correct signal (that no tool is detected) from sensors 110 programmed to detect for tool absence during tool return. On the other hand, the decoder 106 will send an error message that a wrong tool is returned if the reserved sensors 110 are incorrectly triggered. This happens if any of the sensors 110 in the activated positive logic state transmit a signal that a tool is absent; any of the sensors 100 in the negative logic state transmit a signal that a tool is present; or both. The decoder 106 is programmed to disregard signals received from the vacant sensors 112.

[052] To illustrate, Figure 1 shows that a total of 11 sensors are reserved during initialisation to store the tool 106, with all 11 sensors designated to be in the activated positive logic state. The remote terminal 108 thus expects for all the 11 reserved sensors 110 to detect tool presence during tool return shown in Figure 3. However, during tool return, a tool that contacts all 11 sensors is not returned, but a smaller tool 316 that only contacts 7 out of the 11 sensors (the sensors denoted as “G”). The 7 sensors 320 do not send an error signal as they detect tool presence. However, each of the other 4 sensors 322 (also denoted as “R”) sends an error signal due to tool absence. The overall effect is that the reserved sensors 110 (confer Figure 1) are incorrectly triggered. The remote terminal 108 will send an error signal to flag that a wrong tool 316 is returned.

[053] Figure 4 illustrates the board 100 having been configured, during tools training / board 100 initialisation, to store the tool 116 (confer Figure 1), along with the tools 418 and 420 (shown in Figure 5). The response of the board 100 during the return of the incorrect tool 316 was discussed with respect to Figure 3 and is thus not further elaborated.

[054] To store tool 418, more sensors may be reserved than required. In Figure 4, a 4 by 5 sensory array 422 (for a total of 20 sensors) is reserved for storing the tool 418, which only lies on sensors 2, 3, 4, 6, 7, 8, 10, 11, 12, 13, 14 and 18. The tool 418 thus only contacts a total of 12 sensors.

[055] In a first implementation, sensors 2, 3, 4, 6, 7, 8, 10, 11, 12, 13, 14 and 18 may be programmed to be in the activated positive logic state while the remaining sensors 1, 5, 9, 15, 16, 17, 19 and 20 may be programmed to be in the activated negative logic state. If a wrong tool (not shown) is returned which causes any of the activated positive logic state sensors to not detect presence of a tool (for example, sensors 3 and 4), the overall effect is that the reserved sensors are incorrectly triggered. The decoder 106 will then send an error message that a wrong tool is returned.

[056] If a wrong tool is returned which causes all the activated positive logic state sensors to detect tool presence, but also any of the activated negative logic state sensors to detect presence of a tool (for example, sensors 19 and 20), the overall effect is that the reserved sensors are incorrectly triggered. The decoder 106 will still send an error message that a wrong tool is returned.

[057] In a second implementation, the learning algorithm may only have a selection of the sensors on which tool Y lies programmed to be in the activated positive logic state, such as sensors 2, 4, 7, 11, 14

and 18. The other sensors 3, 6, 8, 10, 12 and 13 are programmed to be in the null state. The remaining sensors 1, 5, 9, 15, 16, 17, 19 and 20 may be programmed to be in the activated negative logic state.

[058] If any of the activated positive logic state sensors detect tool absence during tool return (example only sensors 4, 11 and 14, but not sensors 2, 7 and 18), the decoder 106 will still send an error message that a wrong tool is returned because the reserved sensors are incorrectly triggered. If all the activated positive logic state sensors detect tool presence, but any of the activated negative logic state sensors also detect presence of a tool, it would be another instance of the reserved sensors being incorrectly triggered. The decoder 106 will still send an error message that a wrong tool is returned. The null state sensors 3, 6, 8, 10, 12 and 13 will not send a signal, regardless of tool presence or absence.

[059] The second implementation is advantageous to prevent attempts at deriving the combination of sensors to deceive the board 100 that a correct tool has been returned.

[060] A 2 by 4 sensory array 424 (for a total of 8 sensors) may be reserved for storing tool 420, which does not lie flush when resting on the board 100 (see cross section view of Figure 5). Tool 424 is in contact with sensors 25, 26, 31 and 32, but not sensors 27 to 30.

[061] During tools training / board 100 initialisation, the learning algorithm detects that a tool is not in contact with sensors 27 to 30 and may program them to be in the activated negative logic state. The remaining sensors 25, 26, 31 and 32 may then be programmed to have a combination of sensors in the activated positive logic state or in the null state.

[062] If any of the activated negative logic state sensors 27 to 30 detect tool presence during tool return (example sensors 27 and 28), the decoder 106 will still send an error message that a wrong tool (not shown) is returned because the reserved sensors are incorrectly triggered. If all the activated negative logic state sensors 27 to 30 detect tool absence during tool return, but any of the activated positive logic state sensors within sensors 25, 26, 31 and 32 detect tool absence, the decoder will still send an error message that a wrong tool is returned because the reserved sensors are incorrectly triggered. The null state sensors within sensors 25, 26, 31 and 32 will not send a signal, regardless of tool presence or absence.

[063] A trained board 100 can be re-initialised / reset, providing a means to periodically rearrange the reserved sensors for each of the tools on the board 100 to prevent attempts at deriving the combination of sensors where placing a wrong tool could deceive the array of sensors that the correct tool has been returned. The tools are kept in their original locations during this re-initialisation.

[064] Using the sensors reserved for the array 422 as an example, if the sensors 3, 6, 8, 10, 12 and 13 are at present in the null state, resetting the board 100 may result in one or more of them being changed to the positive logic state. If the sensors 2, 4, 7, 11, 14 and 18 are at present in the positive logic state, rearrangement may result in one or more of them being changed to the null state. If the sensors 1, 5, 9, 15, 16, 17, 19 are at present in the activated negative logic state, resetting the board 100 may result in one or more of them being changed to the null logic state. If the sensors 1, 5, 9, 15, 16, 17, 19 are at

present in the null state, rearrangement may result in one or more of them being changed to the negative logic state.

[065] During the resetting of the board 100, an area of the board 100 set aside for the reserved sensors may stay the same or change. When the reserved sensors (i.e. the number of sensors reserved for the tool) stay the same, a boundary within which the reserved sensors fall remains the same before and after rearrangement of the reserved sensors. When the reserved sensors (i.e. the number of sensors reserved for the tool) change, a boundary within which the reserved sensors fall changes before and after rearrangement of the reserved sensors. In both instances, the location of the boundary on the board 100 remains the same.

[066] The tool storage system of the present invention also allows for monitoring of tools kept in peripheral storage, such as an auxiliary toolbox 626 shown in Figure 6. The auxiliary toolbox 626 may have rollers to facilitate mobility. The auxiliary toolbox 626 is in wireless communication 624 with the remote terminal 108 via a wireless tag based on, e.g., via Bluetooth, WiFi or NFC technology.

[067] The auxiliary toolbox 626 provides a means to store a subset of tools from the board 100 and is useful in scenarios where only a selection of tools stored on the board 100 is required for a project. For example, a project may only need 10 pieces of tools, with these 10 pieces of tools removed from the board 100 and placed into the auxiliary toolbox 626 to be carried away for the job.

[068] The remote terminal 108 tracks tools removed from the array of sensors 104 by tallying a record of the weight of each tool stored on the board 100 (one of the tool details saved in the data storage 120, as mentioned above) against the weight reading of a weight sensor provided in the auxiliary toolbox 626 and recording the auxiliary toolbox 626 in which the removed tool is placed, both explained in greater detail with Figure 7 below.

[069] Figure 7 shows a flowchart when tools are drawn from the board 100 and placed into an auxiliary toolbox 626 assigned to a user. At step 702, the user logs in (for example at the remote terminal 108 or a computer terminal at the board 100) with his ID (such as an employee tag or identity access card). At step 704, an identifier (such as a serial number) of the auxiliary toolbox 626 will be captured when brought into proximity with the board 100 by way of, for example, Bluetooth or NFC. The user ID, the auxiliary toolbox ID and the board ID will be indexed together in a database 718. This database may be the same as the one used in the data storage 120 to store tool details, although in another approach, both are separate databases.

[070] Step 706 occurs when the user removes tools from the board 100. The board 100 will communicate to the remote terminal 108 the sensors that are now vacant for the remote terminal 108 to identify the removed tools / part numbers.

[071] Step 708 occurs when the user places the removed tools into the auxiliary toolbox 626. The weight sensor in the auxiliary toolbox 626 will then measure the weight of the tools placed into the auxiliary toolbox 626.

[072] In step 710, the weight reading is compared to the recorded weight of the removed tools / part numbers identified in step 706. In one approach, the weight reading is communicated to the remote terminal 108 to perform the comparison.

[073] Step 712 occurs if the comparison of step 710 is a match (i.e. the weight reading tallies with the recorded weight). A signal is sent in step 714 to update the database 718 that the removed tools are registered as being loaned to the user, whereby the remote terminal 108 can trace the auxiliary toolbox 626 in which the removed tools / part numbers are placed; and the user who loaned them. The flowchart then ends in step 720.

[074] On the other hand, step 716 occurs if the comparison of step 710 is a mismatch (i.e. the weight reading does not tally with the recorded weight, which could occur due to, for example, the weight sensor in the auxiliary toolbox 626 being affected by external vibrations). A notification appears (such as an error message displayed in the remote terminal 108 or the computer terminal at the board 100; or an error light activating at the board 100) to convey the mismatch. Step 716 occurs when the user returns the removed tools to their assigned locations on the board 100. The board 100 then returns to the status of step 706 to await detection of tool removal.

[075] Figure 8 shows a flowchart when tools are returned to the board 100 from an auxiliary toolbox 626. At step 802, the user logs in (for example at the remote terminal 108 or a computer terminal at the board 100) with his ID (such as an employee tag or identity access card). At step 804, an identifier (such as a serial number) of the auxiliary toolbox 626 will be captured when brought into proximity with the board 100 by way of, for example, Bluetooth or NFC. The auxiliary toolbox ID and the board ID will be transmitted to a database 822 for monitoring tools kept in peripheral storage. This database 822 may be the same as the one used in the data storage 120 to store tool details, although in another approach, both are separate databases. The database 822 will cross reference that the user ID received at step 802 and the received auxiliary toolbox ID and the board ID matches with indexed user ID, the auxiliary toolbox ID and the board ID in the database (see 718 of Figure 7).

[076] Step 806 occurs when the user returns tools from the auxiliary toolbox 626 onto the board 100 and their weight is computed as follows. In steps 808 and 810, the board 100 will communicate to the remote terminal 108 to identify the returned tools / part numbers from the sensors on which tools are returned to obtain each of their respective weights while the weight sensor in the auxiliary toolbox 626 will communicate the detected decrease in the weight of the tools placed into the auxiliary toolbox 626. As each tool is returned, the decrease in weight of the tools in the auxiliary toolbox 626 is compared in step 812 against the weight of the tool returned to the board 100.

[077] Step 814 occurs if the comparison of step 812 is a mismatch (i.e. the reduction in the weight reading does not tally with the recorded weight of the tool / part number assigned to the sensors to which the tool is returned), such as from the user returning a tool that does not belong to the board 100. A notification appears (such as an error message displayed in the remote terminal 108 or the computer terminal at the board 100; or an error light activating at the board 100) to convey the mismatch. The

notification serves to alert the user to check whether they have returned the correct tools to the board 100. Upon removal of the mismatched tools, the board 100 returns to the status of step 806 to await detection of tool return.

[078] On the other hand, step 816 occurs if the comparison of step 814 is a match (i.e. the reduction in the weight reading tallies with the recorded weight of the tool / part number assigned to the sensors to which the tool is returned). A signal is sent in step 820 to update the database 822 that a correct tool is returned to the board 100.

[079] After the user returns all tools correctly, they may log out at step 818. The flowchart then ends in step 824.

[080] A "mother / child" relationship is thus established between the board 100 and the auxiliary toolbox 626 which allows monitoring of the number of tools that are being withdrawn from the "mother" board 100 and placed into the "child" auxiliary toolbox 626. The use of a weight sensor in the auxiliary toolbox 626 is also advantageous for compactness, since the auxiliary toolbox 626 may not have enough space to house a sensor board. Upon returning tools from the auxiliary toolbox 626 to the board 100, the remote terminal 108 will verify if the correct tools are being returned from the signals received from the decoder 106 in the manner described above with respect to Figures 3 to 5. If in the event of a missing tool or a wrong tool being returned, the remote terminal 108 will display a warning message of which tool is incorrect or missing.

[081] Figure 9 shows a flow chart 900 for tools training / board 100 initialisation. Figure 9 is described in conjunction with Figures 1 and 2 as follows.

[082] Board initialisation starts at step 902 and proceeds with tool training at step 904. In an automated approach, tools are laid spaced apart over the board 100 with the array of sensors 104. The decoder 106 communicates with the sensors 104 to learn which of them detect a tool thereon to determine which are the ones to be reserved for tool storage; and which are unoccupied / vacant. In a manual approach, co-ordinates for the reserved sensors 110 and the vacant sensors 112 are provided through the remote terminal 108, where it is optional for the tools to be present on the sensors 104. Both the automated and manual approaches thereby result in sensors being activated in step 906.

[083] As the sensors are activated, status lights on the tool cabinet 200 turn yellow to reflect that sensors are collecting, at step 908, data about the tools, like their shape and size to build a database at step 910 for a learning logic program to use to determine the number of sensors that need to be reserved to store a tool. Testing and evaluation occur at step 912, whereby step 910 is reiterated to ensure that the reserved sensors can accurately detect for tool presence. Reiteration stops at step 914 when the database has enough datasets to draw from to determine an arrangement of sensors that need to be reserved for tools placed on the board 100.

[084] At step 916, the learning logic algorithm is programmed with the location of reserved sensors 110 (along with which of them are in a positive logic state, negative logic state or null state) and vacant

sensors 112 and saved. The learning algorithm will also be provided with details of the tools stored on the reserved sensors 110. The learning algorithm ends at step 918.

[085] Figure 10 shows a flow chart 1000 for removal and retrieval of tools from an initialised board 100. Figure 10 is described in conjunction with Figures 1 and 2 as follows.

5 [086] The learning logic program (see step 716 of Figure 7) will detect whether a correct tool is returned, which is reflected by the status lights on the tool cabinet 200 turning a green or red. If the user returns the correct tool, the status light is green, else the status light is red.

[087] The flow chart initiates at step 1002. A user is requested to log in at step 1004 using, for example, using a RFID card at the tool cabinet 200. The remote terminal 108 or the tool cabinet 200 determines
10 whether the user is registered at step 1006. If the user is not recognised, access is denied and the flow chart returns to step 1004.

[088] If the user is recognised, they are granted access to the board 100 and the flow chart advances to step 1010. The remote terminal 108 will detect, through the decoder 106, whether there are tools on the board 100.

15 [089] If there is at least one tool on the board 100, step 1008 occurs where a green light appears at the tool cabinet 200. At step 1014, the board 100 detects whether any of the tools are withdrawn. Step 1016 occurs if tool(s) is withdrawn and the remote terminal 108 records the tool(s) that are withdrawn. If no tool is withdrawn, the end 1026 occurs.

[090] Returning to step 1010, if there are no tools on the board 100, step 1012 occurs where a red
20 light will appear at the tool cabinet 200. At step 1018, the board 100 detects whether any tools are returned. If no tool is returned, the end 1026 occurs. Step 1020 occurs if a tool is returned, where the sensors on which the tool is placed sends a signal to the remote terminal 108 at step 1022 on whether they are triggered correctly. At step 1024, the remote terminal receives the signal. The end 1026 occurs if the sensors detect that a correct tool is returned. If the sensors are triggered incorrectly, step 1012
25 occurs where a red light will appear.

[091] A possible operation sequence of the tool storage system of the present invention is as follows.

- a) Start with the board 100 having the array of sensors 104
- b) Place tools on the board 100 simultaneously
- c) The tool board 100 determines which of its array of sensors detects a tool lying thereon.
- 30 d) The learning algorithm determines the location of the sensors that have a tool thereon. The learning algorithm designates these sensors as reserved for tool storage and the remaining sensors as being unoccupied / vacant. The location of the sensors is saved, and the tool / part number is entered.
- e) A foam pad with shapes cut-out at the learnt placements is then placed onto the board 100. The decoder 106 will disregard signals from sensors on which the foam lie for being designated as being
35 unoccupied / vacant in step d). Sensors on the board corresponding to the cut-out locations detect for tool removal and return.

f) If a tool returned to the cutout location does not trigger the correct sensors reserved for tool storage, the board will send a signal that a wrong tool has been returned.

[092] Figure 11 depicts components of the remote terminal 108 shown in Figure 1.

[093] As shown in Figure 11, the example remote terminal 108 includes a processor 1104 for executing software routines. Although a single processor is shown for the sake of clarity, the remote terminal 108 may also include a multi-processor system. The processor 1104 is connected to a communication infrastructure 1106 for communication with other components of the remote terminal 108. The communication infrastructure 1106 may include, for example, a communications bus or network.

[094] The remote terminal 108 further includes a main memory 1108, such as a random access memory (RAM), and a secondary memory 1110. The secondary memory 1110 may include, for example, a hard disk drive 1112, a removable storage drive 1114 (which may be a USB flash drive, a flash memory device, a solid state drive or a memory card). As will be appreciated by persons skilled in the art, the hard disk drive 1112 and the removable storage drive 1114 can store computer executable program code instructions and/or data.

[095] The remote terminal 108 also includes at least one communication interface 1124. The communication interface 1124 allows software and data to be transferred between the remote terminal 108 and external devices via a communication path 1126. In various embodiments of the inventions, the communication interface 1124 permits data to be transferred between the remote terminal 108 and a data communication network, such as a public data or private data communication network. The communication interface 1124 may be used to exchange data between other remote terminals (not shown) so that the remote terminals form part of an interconnected computer network. Examples of a communication interface 1124 can include a modem, a network interface (such as an Ethernet card), a communication port (such as a serial, parallel, printer, GPIB, IEEE 10394, RJ45, USB), an antenna with associated circuitry and the like. The communication interface 1124 may be wired or may be wireless. Software and data transferred via the communication interface 1124 are in the form of signals which can be electronic, electromagnetic, optical or other signals capable of being received by communication interface 1124. These signals are provided to the communication interface via the communication path 1126.

[096] As shown in Figure 11, the remote terminal 108 further includes a display interface 1102 which performs operations for rendering images to an associated display 1130.

[097] Computer programs (also called computer program code) are stored in main memory 1108 and/or secondary memory 1110. Computer programs can also be received via the communication interface 1124.

[098] Software may be stored in a computer program product and loaded into the remote terminal 108 by using the removable storage drive 1114 or the hard disk drive 1112. Alternatively, the computer program product may be downloaded into the remote terminal 108 over the communications path 1126.

The software, when executed by the processor 1104, causes the remote terminal 108 to learn a location of reserved sensors and vacant sensors during initialisation of a board with an array of sensors; receive input providing details of the tool stored on the reserved sensors; detect, from the signals when the board is used, for removal of tools from and return of tools to the reserved sensors; and determine whether to transmit a message that a wrong tool is returned when at least one of the reserved sensors is triggered incorrectly during the tool return.

[099] Figure 13 shows examples of sensors that can be used with the board 100, which include inductance sensors 1302, light sensors 1304 (operating in infra-red, ultraviolet or visible light spectrums), radio frequency sensors 1306 and capacitive sensors 1308. These sensors 1302, 1304, 1306 and 1308 may be configured to realise positive logic state and negative logic state based on how a monitored parameter in each of them reacts to tool presence or absence, explained in further detail below.

[100] The inductance sensor 1302 detects tool presence from monitoring for a change in magnetic flux. In the negative logic state, the decoder 106 is configured to not expect a change in the magnetic flux reading from the inductance sensor 1302 during tool check out and tool return. A change in the magnetic flux reading will indicate tool presence which would result in incorrect triggering. On the other hand, in the positive logic state, the decoder 106 is configured to expect a change in the magnetic flux reading from the inductance sensor 1302 during tool return if the tool is drawn during tool check out. No change in the magnetic flux reading during tool return would result in incorrect triggering because tool presence is expected.

[101] The light sensor 1304 may have, for example, a UV LED transmitter 1310 and receiver 1312 pair. Presence of a tool may be detected from the tool blocking light from the transmitter 1310 to the receiver 1312. In the negative logic state, the decoder 106 is configured to expect the light sensor 1304 to signal that the receiver 1312 is continuously receiving the light. Detection of light blockage will indicate tool presence which would result in incorrect triggering. On the other hand, in the positive logic state, the decoder 106 is configured to expect the light sensor 1304 to signal light blockage during tool return if the tool is drawn during tool check out. No change in the light sensor 1304 reading during tool return would result in incorrect triggering because tool presence is expected.

[102] The radio frequency sensor 1306 acts as a source of power by transmitting a radio wave 1316 to energise a receiver tag 1314 located on a tool (not shown) in proximity to create resonance that is detected by the radio frequency sensor 1306. In the negative logic state, the decoder 106 is configured to not expect a return resonant frequency signal from the radio frequency sensor 1306 during tool check out and tool return. The detection of a return resonant frequency signal will indicate tool presence which would result in incorrect triggering. On the other hand, in the positive logic state, the decoder 106 is configured to expect a return resonant frequency signal from the radio frequency sensor 1306 during tool return if the tool is drawn during tool check out. No change in the radio frequency sensor 1306 reading during tool return would result in incorrect triggering because tool presence is expected.

[103] The capacitive sensor 1308 detects a change in capacitance when a tool 1318 is placed thereon. In the negative logic state, the decoder 106 is configured to not expect a change in the capacitance reading from the capacitive sensor 1308 during tool check out and tool return. A change in the capacitance reading will indicate tool presence which would result in incorrect triggering. On the other hand, in the positive logic state, the decoder 106 is configured to expect a change in the capacitance reading from the capacitive sensor 1308 during tool return if the tool 1318 is drawn during tool check out. No change in the capacitance reading during tool return would result in incorrect triggering because tool presence is expected.

[104] In summary, the decoder 106, the board 100 with the array of sensors 104 and the remote terminal 108 provide the following functions / capabilities:

- i) tools training / board 100 initialisation by placing tools for storage onto the sensor board, serving as the base for the tool tray. Sensor board determines which of its sensors are reserved for tool storage (by detection of a tool thereon) and which are unoccupied / vacant (for not detecting a tool thereon). The purpose of reserving sensors is to assign locations on the board for tool storage, whereby these sensors are then monitored during tool return. The rest of the sensors are then treated as unoccupied / vacant and not monitored for tool return. A layer of foam 1202 (see Figure 12) is then placed on the array of sensors 1204 with cutouts allowing access to the sensors reserved for tool storage. This assists with monitoring of tool return from the cutaways intuitively indicating to the user the assigned locations for tool return.

A simple operation mode may have all reserved sensors in the activated positive logic state, where tools are assessed to be incorrectly returned if any of the reserved sensors detect absence of a tool during tool return.

In an advance operation mode, a combination of activated positive logic state; activated negative logic state and null state sensors are used to assess whether tools are correctly returned. If at least one of the sensors in the activated positive logic state detect absence of a tool during tool return or at least one of the sensors in the activated negative logic state detect presence of a tool during tool return, it is assessed that a wrong tool is returned. The advance operation mode increases the difficulty in deriving the correct combination of sensors to deceive the sensor board that the correct tool has been returned.

In one implementation, the learning algorithm may randomly decide which of the reserved sensors are designated to be in the activated positive logic state; the activated negative logic state; or the null state, provided that the decided combination does not send an error message for a correctly returned tool. After the board 100 is trained, it can be re-initialised through execution of a reset command to relearn the location of the tools that are already on the board 100. The learning algorithm can thus be harnessed using the reset command to periodically change the combination of sensors to make it more difficult to derive from attempts to deceive the sensor board. In another implementation, the combination may be manually selected. For

instance, after the location of the reserved sensors are determined from tools training / board 100 initialisation, the remote terminal may be used to change one or more sensors, designated to be in the activated positive logic state during tools training / board 100 initialisation, to the null state.

- 5 ii) learning of tool placement and labelling of tool type / part number: the location of each set of reserved sensors is saved to demarcate an area of the sensor board reserved for a tool. Each set of reserved sensors is then labelled by indicating the type of tool / part number stored, i.e. a user will enter the tool type / part number that was placed on each location on the sensor board. This builds a record of the tools / part numbers that the tool tray stores and their assigned
- 10 locations. Tools are then secured by a foam board placed on top of sensor board, the foam board having a cutaway for each tool, corresponding to the outline of that tool (see Figure 7 below).
- iii) tool user registration to determine the users who have accessed the tool tray and the tools they have removed
- iv) sensing of tool removal and updating of tool check-out records (to facilitate tracking of users
- 15 and their checked out tools)
- v) verification of correct tool return and placement. If a returned tool does not trigger the correct sensors, it is determined as a wrong tool return. Oversized tools will not be returnable because they cannot fit into the foam cutaway.
- vi) onboarding of additional tools. A new tool / part number may be stored on any part of the sensor
- 20 board having sufficient space. Dimensions of the new tool / part number and its intended storage location on the sensor board can be sent to a remote terminal, to reserve the required number of unoccupied / vacant sensors at the intended storage location. The new tool / part number is entered and the record of the tools / part numbers that the tool tray stores is updated. The existing foam board needs to be modified by removing the portion of foam through which the
- 25 new tool / part number is to be inserted. An error message will issue if the placed tool does not match the number of reserved sensors during the process of onboarding an additional tool.
- vii) relocation of existing tool placement. The location of existing tools can be rearranged. The reserved sensors at the existing locations are released (i.e., no longer reserved), while the required number of unoccupied / vacant sensors at the new locations for the tools to be relocated
- 30 are reserved to store the relocated tools. The existing foam board may need to be replaced with a new foam board. The record of the tools / part numbers that the tool tray stores is updated.
- viii) a "mother / child" relationship with auxiliary storage used to store a subset of tools from the sensor board. The weight of tools in the auxiliary storage is used to track tool movement by tallying against weight records of the tools removed from the sensor board.

35 [105] In the application, unless specified otherwise, the terms "comprising", "comprise", and grammatical variants thereof, intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, non-explicitly recited elements.

[106] While this invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes can be made and equivalents may be substituted for elements thereof, without departing from the scope of the invention. In addition, modification may be made to adapt the teachings of the invention to situations and materials, without
5 departing from the essential scope of the invention. Thus, the invention is not limited to the examples that are disclosed in this specification but encompasses all embodiments falling within the scope of the appended claims.

CLAIMS

1. A tool storage system comprising:
 - a board with an array of sensors, each configurable to be reserved for tool storage or
5 vacant;
 - a decoder to monitor usage of the array of sensors;
 - a remote terminal to process signals received by the decoder, the remote terminal configured to:
 - learn a location of the reserved sensors and the vacant sensors from the signals received
10 during initialisation of the board;
 - receive input providing details of the tool stored on the reserved sensors;
 - detect, from the signals when the board is used, for removal of tools from and return of tools to the reserved sensors; and
 - determine whether to transmit a message that a wrong tool is returned when the decoder
15 relays that at least one of the reserved sensors is triggered incorrectly during the tool return; and
 - a data storage to save details of the tool stored by the reserved sensors, the location of the reserved sensors, and the location of the vacant sensors; and
 - wherein the reserved sensors comprise sensors in a positive logic state configured to expect tool presence during tool return; and sensors in a negative logic state configured to
20 expect tool absence during tool return.
2. The tool storage system of claim 1, wherein the reserved sensor incorrectly triggers if during tool return the reserved sensor returns a status that is contrary to designation during initialisation.
- 25 3. The tool storage system of claim 1 or 2, wherein the incorrect triggering occurs when the sensor in the positive logic state detects tool absence during the tool return or the sensor in the negative logic state detects tool presence during the tool return.
4. The tool storage system of claim 3, wherein the sensors in the positive logic state are further
30 configured to send an error signal when detecting tool absence during the tool return; and the sensors in the negative logic state are further configured to send an error signal when detecting tool presence during the tool return.
5. The tool storage system of any one of the preceding claims, wherein the reserved sensors further
35 comprise sensors in a null state configured to be silent.

6. The tool storage system of any one of the preceding claims, wherein the remote terminal learns the location of the reserved sensors and the vacant sensors through placement of tools on the array of sensors.

7. The tool storage system of claim 6, wherein designation of the reserved sensors to the positive logic state, the negative logic state or the null state is randomly decided.

8. The tool storage system of any one of claims 5 to 7, wherein the remote terminal is further configured to rearrange the reserved sensors for the tools on the board, in response to a reset command.

9. The tool storage system of any one of claims 1 to 5, wherein the remote terminal learns the location of the reserved sensors and the vacant sensors through co-ordinate input.

10. The tool storage system of any one of the preceding claims, wherein the message that a wrong tool is returned is transmitted when one or more of the following occurs: number of the reserved sensors that are triggered incorrectly exceeds a threshold or the reserved sensors that are triggered incorrectly are at a particular location.

11. The tool storage system of any one of the preceding claims, wherein the remote terminal is further configured to:

communicate with a weight sensor to obtain a weight reading; and

compare whether the obtained reading tallies with a weight record of tools removed from or returned to the array of sensors.

12. The tool storage system of claim 11, wherein the weight sensor is provided in an auxiliary toolbox, and wherein the weight reading is of the tools stored in the auxiliary toolbox.

13. The tool storage system of claim 12, wherein the remote terminal is further configured to obtain an identifier of a wireless tag provided in the auxiliary toolbox when brought into proximity with the board.

14. The tool storage system of claim 13, wherein the remote terminal is further configured to record the identifier of the auxiliary toolbox with one or more of an identity of the board, or a user to which the auxiliary toolbox is assigned.

15. The tool storage system of any one of claims 12 to 14, wherein the remote terminal is further configured to transmit an error notification in response to detection of a mismatch between the weight record of the tools removed from or returned to the array of sensors and the weight reading from the weight sensor.

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16. The tool storage system of any one of the preceding claims, wherein the array of sensors comprises capacitive sensors.